Appendix K
Capture Zone Tests and Analysis

DRAFT REPORT

Middletown Airfield Site
Middletown, Pennsylvania

Capture Zone Tests and Analysis

1 July 1996

ERM Program Management Company
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ERM®

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EXECUTIVE SUMMARY

Aquifer tests were conducted on HIA production wells HIA-2, HIA-9, and HIA-13 and Middletown Borough Authority well MID-04 to evaluate the aquifer characteristics in the vicinity of these wells. Each aquifer test consisted of a 72-hour (nominal) pumping or recovery test. Constant-rate pumping tests were conducted on production wells HIA-2 and HIA-9 located in the Eastern and Western areas of the Site, respectively. Recovery tests were conducted on production wells HIA-13 located in the Central area of the site and MID-04 in the North Base Landfill Area.

Prior to conducting the aquifer tests, ambient monitoring of water levels and barometric pressure was performed, on two background wells in each of the four areas, to evaluate fluctuations in the water level under normal conditions. The ambient fluctuations were on the order of 0.5 feet. None of the wells exhibited a response to a rainfall event that occurred during the ambient monitoring period, suggesting that a rainfall event would not significantly impact the pumping tests. Several wells did respond to pumping of the production wells, but the change in water level was sufficiently larger than the ambient fluctuation (0.5 feet) that differentiating between the two was not an issue in the data analysis.

The aquifer test results demonstrated that the transmissivity of the bedrock aquifer increased moving from the North Base Landfill toward the Industrial Area and from east to west within the Industrial Area. The Western portion of the Industrial Area exhibited transmissivity values approximately 25 times greater than the North Base Landfill Area. This is likely the result of increased fracturing in the bedrock in the Western Area. It was expected that anisotropic conditions would be observed (i.e., greater drawdown would be observed in the direction of bedrock strike versus the direction of dip), however, this was not observed in the test results. The response to pumping in wells along strike was similar to the response observed in wells downdip of the pumping well. This may be the result of the spacing and location of observation wells such that they did not intersect the fractures being affected by the pumping.

The results of the capture zone tests were used in the development of a regional ground water flow model to evaluate capture zones for each production well. The analytical element ground water model TWODANTM was used to delineate the capture zones for each well. The model calibration process was accomplished by adjusting the infiltration rate until the simulated water table elevations matched the measured elevations. An average annual infiltration rate of 12 inches/year was used as representative of field conditions in the model calibration and simulation of model scenarios. Once the model was calibrated, it was used to simulate four different pumping scenarios. Scenarios 1,2, and 3 were based on typical HIA well configurations and average daily pumping rates for the active HIA production wells and average annual pumping rates for the Middletown Borough Authority wells. Scenario 4 simulated the average annual pumping rates for all HIA wells and the five Middletown Borough Authority wells. The capture zones for each of the four scenarios were calculated for a 16 year time period.

In all four Scenarios, the HIA production wells receive water from the North and Northeast. Therefore, contaminant sources located to the North may impact the HIA production wells. Well MID-04 draws water from the northwest and the radius of influence extends far enough to the West to influence leachate generated from the North Base Landfill. Both Scenarios 1 and 2 have HIA-13 as the lead well which is the most common configuration. Scenario 3 has HIA-12 as the lead well. In each of these three scenarios, the radius of influence extends south to the Susquehanna River in the Western and Central Areas and to just north of the Runway in the Eastern Area. The extent of the capture zone depicted in these scenarios are based on average daily pumping rates held constant for 16 years and do not reflect the actual "on-demand" operation of the HIA system. The capture zone simulated in Scenario 4 is believed to be more representative of site conditions because it was based on average annual pump rates. The area of influence simulated in Scenario 4 does not extend south of the Runway in the Western and Central Areas or south of Building 100 and the road off of Airport Drive that serves as the northern boundary of the PAANG compound in the Eastern Area. Therefore, contaminants detected south of the HIA-2 area will likely migrate to the Susquehanna River.

K.1 INTRODUCTION AND PROJECT OBJECTIVES

K.1.1 INTRODUCTION

The Capture Zone Aquifer Tests and Analysis were a part of the Supplemental Studies Investigation (SSI) conducted at the Middletown Airfield NPL Site, Pennsylvania. These studies were required by the December 1990 Record of Decision as clarified by April 1992 Explanation of Significant Differences (ESD). This work was conducted under Contract Number DACW 45-93-D-0017, with the USACE Omaha District, Delivery Order Numbers 005, 006, 007, and 008.

The Middletown Airfield NPL Site (Site), formerly the Olmsted Air Force Base, is located in Dauphin County, Pennsylvania, approximately 8 miles southeast of Harrisburg (Figure K-1). The former Air Force field and many of the Air Force buildings are now owned by the Pennsylvania Department of Transportation and operated by the Harrisburg International Airport (HIA), several small private manufacturing companies, and the Air National Guard. Ten production wells (HIA-1, 2, 3, 4, 5, 6, 9, 11, 12, and 13) are operated for water supply at the Site. One additional well, HIA-14, is used exclusively for HVAC purposes. These wells are grouped as followed (see Figure K-2):

- Eastern HIA wells (HIA 1 through 5);
- Central HIA wells (HIA-13);
- Western HIA wells (HIA- 6, 9, 11 and 12)

An additional public water supply well (MID-04) is operated in the vicinity of the North Base Landfill by Middletown Borough Authority (also shown on Figure K-2). A work plan was prepared by ERM and reviewed and approved by EPA and USACE.

K.1.2 PROJECT OBJECTIVES

Potential migration of contamination from the former North Base Landfill and from the Industrial Area is a concern for the Middletown Borough Authority production well MID-04, and for the HIA production wells, respectively. The intent of the ESD was to protect the water supply well MID-04 by installing sentinel wells to warn the Borough should contaminants move toward MID-04 from the North Base Landfill. A wellhead protection study for the Middletown wells was performed by

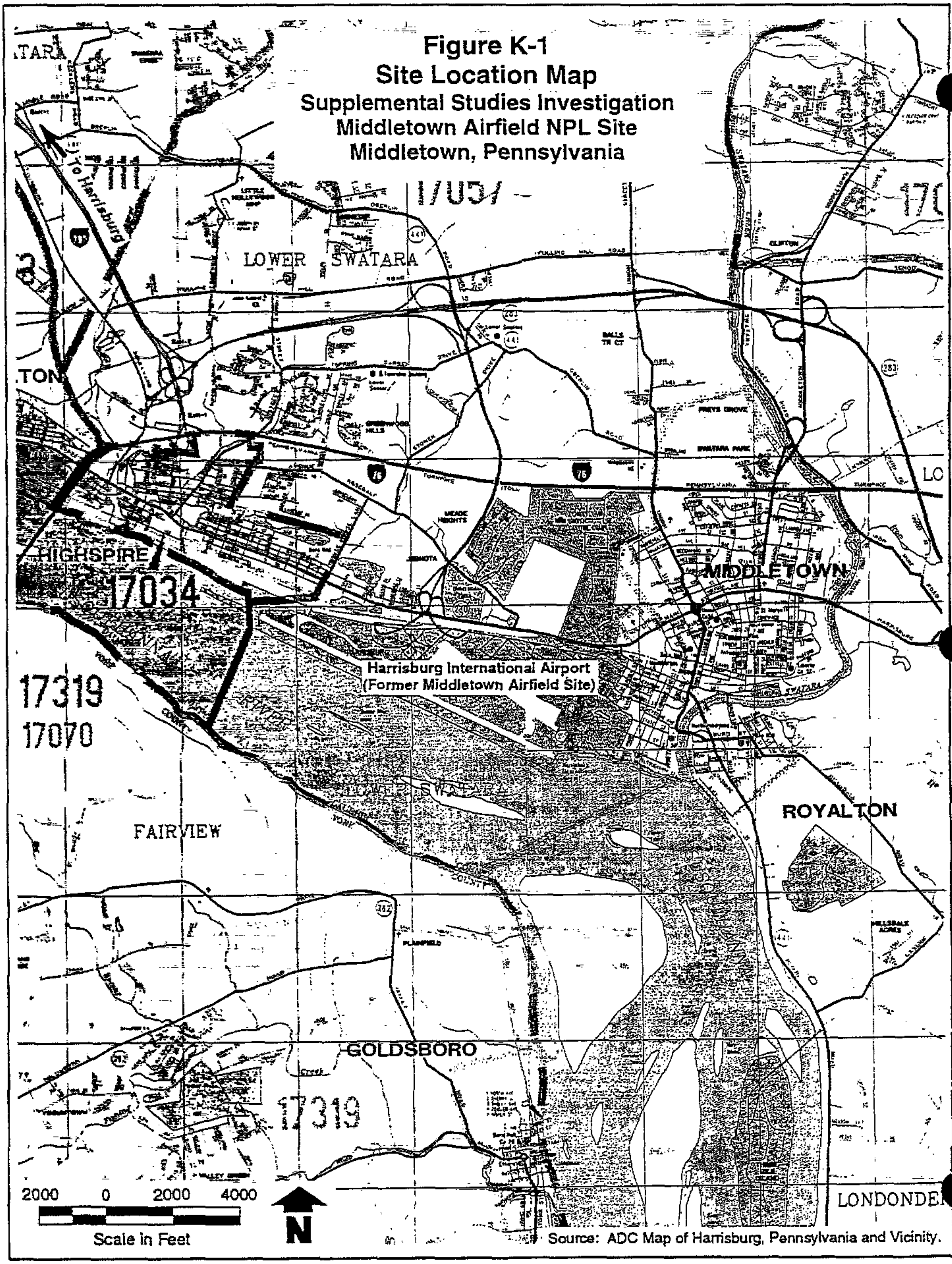
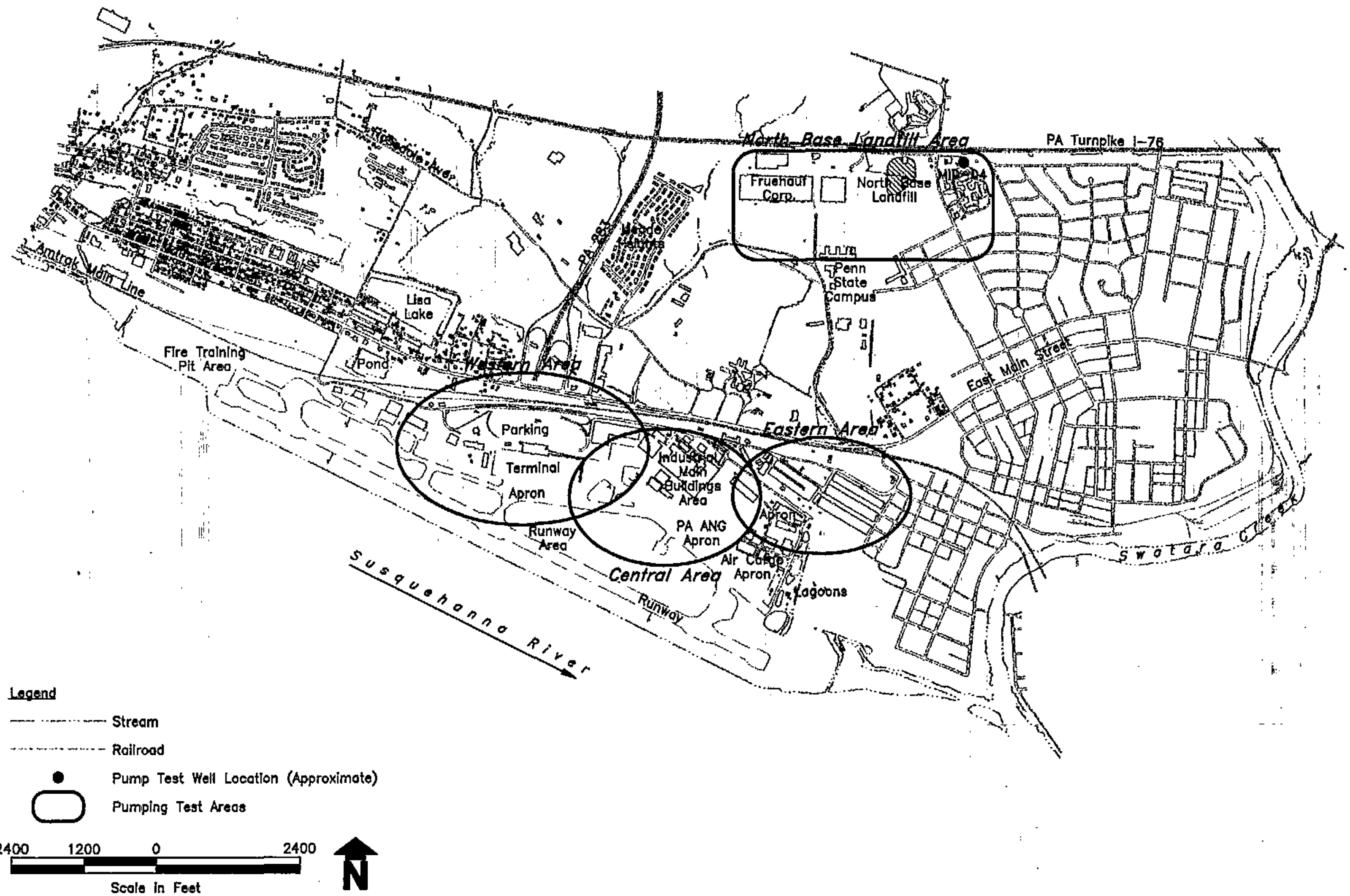


Figure K-1
Site Location Map
Supplemental Studies Investigation
Middletown Airfield NPL Site
Middletown, Pennsylvania
To Harrisburg
LOWER SWATARA
HIGHSPIRE
17034
17319
17070
FAIRVIEW
Harrisburg International Airport
(Former Middletown Airfield Site)
MIDDLETOWN
ROYALTON
GOLDSBORO
17319
2000 0 2000 4000
Scale in Feet
N
Source: ADC Map of Harrisburg, Pennsylvania and Vicinity.

Figure K-2
Capture Zone Test Location Areas
Middletown Airfield NPL Site
Middletown, Pennsylvania



GeoServices, Ltd. for Middletown Borough Authority in 1992, but did not include monitoring of local wells and/or piezometers.

In order to evaluate these concerns, four capture zone tests were conducted to evaluate the capture zones of the public supply wells. Each aquifer test consisted of a 72 hour (nominal) pumping test or recovery test, including water level monitoring of appropriate site wells and data analysis to determine the area of influence for each well.

Capture zone analyses were performed to help determine whether pumping of these production wells may have resulted in contaminant migration from the North Base Landfill or the Industrial Area toward these wells. The ground water model TWODAN™ was used to delineate the capture zones of the HIA production wells and MID-04.

K.1.3 SCOPE OF WORK

The capture zone testing consisted of four aquifer tests, three on HIA production wells (HIA-2, HIA-9, and HIA-13), and one on Middletown Borough Authority well MID-04. The HIA production wells are located in three different areas of the Site; the Eastern area, Central area, and Western area. Well MID-04 is located in the vicinity of the North Base Landfill. *Figure K-2 shows the aquifer test location areas for the capture* zone analysis. Each aquifer test was performed independently as detailed in the Section K.3. General procedures for the pumping test are detailed in Section K.3.1. Analyses of the pumping tests are presented in Section K.4.

A regional ground water flow model was used to determine the capture zones of the HIA production wells and Middletown Borough Authority well, MID-04. A 2-dimensional model, covering an area of over 14 square miles, was developed using the analytical element program, TWODAN™. First, a conceptual model of the regional aquifer was developed based on regional and site-specific geologic, hydrogeologic, and climatic information. The analytic element model was then constructed and calibrated to measured water levels within the Site area. The capture zone for each of the production wells was then simulated using the average annual pumping rate of each well. The capture zone analysis is detailed in Section K.5.

As a part of this study, nested wells were installed within 100 feet of the three HIA production wells for the purpose of monitoring the capture zone tests. The locations of these wells were selected based on the strike and dip of the bedrock in an attempt to observe anisotropy within the aquifer during the tests. The final well locations were determined by the location of underground utilities and the available space to drill with the least impact to vehicular traffic. These capture zone well nests were designated ERM-21, ERM-22, ERM-23, ERM-24, ERM-25, and ERM-26. Each well nest consists of three wells referenced as shallow (S), intermediate (I), and deep (D). The shallow wells were completed in the overburden with a screened interval of 10 to 20 feet below ground surface (bgs). The intermediate wells were completed in bedrock with a screened interval of 160 to 200 feet bgs, and the deep wells were typically screened from 555 to 595 feet bgs. Tables K-1 and K-2 summarize the construction information for the site monitoring wells and the production wells, respectively.

The sentinel wells installed in the vicinity of MID-04 served as monitoring wells for this aquifer test. The sentinel well nests (ERM-7, ERM-8, and ERM-9) each consisted of shallow (150 ft bgs), intermediate (350 ft bgs) and deep (670 ft bgs) wells. The screened interval for the shallow wells was 20 feet. The intermediate and deep wells have 40 ft screened intervals. All the sentinel wells were constructed of 4-inch diameter stainless steel.

Table K-1
Monitoring Well Construction Details
Middletown Airfield NPL Site

Location of Well	Well I.D.	PA State Grid Coordinates Northing (Y)	Easting (X)	Elevation Top of Casing (MSL)	Land Surface Elevation (MSL)	Well Depth (feet BLS)	OB/ BR Well	Sand Pack Interval (feet BLS)	Screen Inverval (feet BLS)	Well Diamter/ Material (in.)	
Main	ERM-1S	314378.286	2249355.178	295.22	295.61	13.46	OB	2.5-15.0	3.0-13.0	2	pvc
Building	ERM-1I	314344.186	2249365.167	294.96	295.23	98.65	BR	74.0-99.7	78.58-98.58	2	pvc
/Lagoon	ERM-2S	316176.579	2247768.215	298.29	298.74	16.86	OB	6.0-18.5	8.0 - 18.0	2	pvc
Area Wells	ERM-3S	316445.448	2247133.293	300.96	301.27	16.58	OB	6.0-22.0	7.0 - 17.0	2	pvc
	ERM-4S	316330.819	2246957.705	299.57	299.88	19.60	OB	7.0-19.5	9.0-19.0	2	pvc
	ERM-5S	316147.920	2247207.383	297.26	297.85	19.35	OB	8.0-20.5	10.0-20.0	2	pvc
	ERM-6S	316441.710	2246844.150	302.36	303.09	23.50	OB	12.5-25.0	14.5 -24.5	2	pvc
	ERM-10I	316144.025	2245931.468	301.00	301.30	99.85	BR	78.0-102.0	80.0-100.0	2	pvc
	ERM-27S	315859.981	2246901.946	300.93	298.43	22.76	OB	7.5-20.0	9.5 - 19.5	2	pvc
	ERM-28S	315761.841	2248309.090	298.55	299.29	21.45	BR	9.5-22.0	11.5-21.5	2	pvc
	ERM-32I	315945.980	2247069.883	297.31	297.54	100.10	BR	77.5-102.5	80.0-100.0	2	pvc
	ERM-32D	315954.245	2247076.989	297.25	297.55	300.00	BR	276.0-302.0	280.0-300.0	4	pvc
	ERM-33I	315819.038	2247796.296	297.09	297.47	131.89	BR	107.0-142.0	112.0-132.0	2	pvc
	ERM-34S	314672.408	2248431.190	297.07	297.45	17.50	OB	6.0-19.25	8.2-18.2	2	pvc
	ERM-34I	314685.336	2248438.721	297.06	297.42	99.90	BR	77.0-102.0	80.0-100.0	2	pvc
	ERM-35S	313534.168	2248575.260	299.33	299.57	19.37	OB	7.0-20.5	9.5-19.5	2	pvc
	ERM-35I	313519.399	2248593.370	299.04	299.39	99.78	BR	77.4-102.0	80.0-100.0	2	pvc
Capture	ERM-21S	316045.223	2244344.825	303.44	303.79	34.83	BR	24.0-36.0	25.5-35.5	2	pvc
Zone	ERM-21I	316000.455	2244326.514	303.08	303.30	199.76	BR	155.0-202.0	160.0-200.0	4	SS
Wells	ERM-21D	316022.951	2244333.713	303.23	303.53	599.17	BR	552.0-603.0	557-597	4	SS
	ERM-22S	316096.643	2244163.645	308.37	308.63	43.07	BR	31.0-44.2	33.5-43.5	2	pvc
	ERM-22I	316144.473	2244186.030	309.21	309.47	199.47	BR	157.0-202.0	160.0-200.0	4	SS
	ERM-22D	316131.586	2244168.720	308.41	308.68	599.13	BR	552.0-603.0	557.0-597.0	4	SS
	ERM-23S	316159.331	2246605.563	301.47	301.66	24.44	OB	13.0-26.0	15.0-25.0	2	pvc
	ERM-23I	316163.826	2246592.153	301.45	301.74	196.58	BR	149.0-200.0	155.0-195.0	4	SS

Table K-1
Monitoring Well Construction Details
Middletown Airfield NPL Site

Location of Well	Well I.D.	PA State Grid Coordinates Northing (Y)	Easting (X)	Elevation Top of Casing (MSL)	Land Surface Elevation (MSL)	Well Depth (feet BLS)	OB/ BR Well	Sand Pack Interval (feet BLS)	Screen Inverval (feet BLS)	Well Diamter/ Material (in.)	
	ERM-23D	316156.299	2246617.995	301.70	301.83	593.59	BR	547.0-602.0	553.0-593.0	4	SS
	ERM-24S	316106.946	2246713.362	299.97	300.27	24.39	OB	12.1-25.0	14.7-24.7	2	pvc
	ERM-24I	316139.375	2246723.309	300.05	300.40	199.07	BR	157.0-202.0	160.0-200.0	4	SS
	ERM-24D	316126.382	2246712.314	300.12	300.38	598.85	BR	553.0-603.0	557-597	4	SS
	ERM-25S	315974.625	2249256.845	330.04	330.39	45.45	BR	32.9-48.1	36.2-46.2	2	pvc
	ERM-25I	315977.872	2249244.097	330.20	330.40	189.91	BR	157.0-202.0	160.0-200.0	4	SS
	ERM-25D	315981.387	2249230.161	330.16	330.50	599.19	BR	553.0-603.0	558.0-598.0	4	SS
	ERM-26S	315840.197	2249223.525	331.25	331.53	45.97	BR	34.0-46.3	36.0-46.0	2	pvc
	ERM-26I	315847.957	2249212.164	331.28	331.51	200.06	BR	157.0-202.0	160.0-200.0	4	SS
	ERM-26D	315829.719	2249236.334	331.11	331.35	599.92	BR	556.0-602.0	560.0-600.0	4	SS
Runway	ERM-18S	315338.485	2246180.109	301.98	302.50	19.72	OB	8.0-21.0	10.5 - 20.5	2	pvc
Wells	ERM-18I	315348.706	2246154.608	302.18	302.41	120.22	BR	97.0-122.5	100.0-120.0	2	pvc
	ERM-19S	314014.853	2247842.987	299.72	300.11	18.79	OB	6.8-19.5	9.0-19.0	2	pvc
	ERM-20S	312837.385	2247694.238	301.11	301.37	25.37	OB	13.0-26.0	15.8 - 25.8	2	pvc
	ERM-20I	312844.821	2247680.220	301.04	301.31	119.80	BR	97.0-123.0	100.0-120.0	2	pvc
North	ERM-11S	319385.531	2250412.001	368.73	368.92	24.69	BR	13.0-25.5	15.0 - 25.0	2	pvc
Base	ERM-11I	319443.928	2250416.283	370.34	370.67	99.79	BR	77.0-101.0	80.0-100.0	2	pvc
Landfill	ERM-12S	319688.795	2250869.015	379.40	379.67	20.61	BR	9.0-22.0	11.0-21.0	2	pvc
Wells	ERM-12I	319634.279	2250863.556	379.17	379.36	100.12	BR	75.5-102.0	80.0-100.0	2	pvc
	ERM-13S	320360.861	2250280.590	383.12	383.38	21.62	BR	20.0-33.5	22.0-32.0	2	pvc
	ERM-13I	320348.327	2250282.801	382.98	383.22	101.25	BR	75.0-102.0	80.0-100.0	2	pvc
	ERM-14S	320612.957	2250297.620	384.08	384.41	33.00	BR	20.0-34.5	23.5-33.5	2	pvc
	ERM-14I	320627.333	2250294.716	384.82	385.04	107.70	BR	76.5-102.0	80.0-100.0	2	pvc
	ERM-15I	321210.093	2250833.489	399.15	399.50	99.70	BR	75.0-102.0	80.0-100.0	2	pvc

Table K-1
Monitoring Well Construction Details
Middletown Airfield NPL Site

Location of Well	Well I.D.	PA State Grid Coordinates Northing (Y)	Easting (X)	Elevation Top of Casing (MSL)	Land Surface Elevation (MSL)	Well Depth (feet BLS)	OB/ BR Well	Sand Pack Interval (feet BLS)	Screen Inverval (feet BLS)	Well Diamter/ Material (in.)	
	ERM-16S	319947.658	2249389.440	377.33	377.59	43.97	BR	30.0-46.0	34.0-44.0	2	pvc
	ERM-16I	319932.282	2249388.275	377.24	377.49	101.14	BR	76.0-102.0	80.0-100.0	2	pvc
	ERM-17S	319963.100	2248544.060	377.22	377.56	44.59	BR	31.0-46.0	35.0-45.0	2	pvc
	ERM-17I	319962.544	2248560.343	377.31	377.54	101.17	BR	78.0-102.0	80.0-100.0	2	pvc
	ERM-29S	319540.511	2248395.300	376.53	376.82	45.16	BR	32.5-46.0	34.5-44.5	2	pvc
	ERM-29I	319548.278	2248389.370	376.61	376.96	99.78	BR	76.0-102.0	80.0-100.0	2	pvc
	ERM-30S	319247.863	2249399.930	366.73	367.01	19.53	BR	8.0-21.5	10.0-20.0	2	pvc
	ERM-30I	319246.277	2249416.060	366.84	367.06	100.10	BR	76.0-102.0	80.0-100.0	2	pvc
	ERM-31I	319796.530	2250820.520	377.99	378.40	200.32	BR	176.5-202.0	180.0-200.0	2	pvc
Sentinel Wells	ERM-7S(SENT)	320642.631	2251571.913	408.03	408.39	146.72	BR	120.0-152.0	123.0-143.0	4	SS
	ERM-7I(SENT)	320663.185	2251560.205	408.46	408.74	333.71	BR	288.0-352.0	294.0-334.0	4	SS
	ERM-7D(SENT)	320683.756	2251548.749	409.62	409.99	643.35	BR	594.0-678.5	603.0-643.0	4	SS
	ERM-8S(SENT)	320459.607	2251643.771	409.69	409.96	124.57	BR	102.0-130.0	105.0-125.0	4	SS
	ERM-8I(SENT)	320475.911	2251638.523	409.24	409.50	343.80	BR	295.5-352.0	302.0-342.0	4	SS
	ERM-8D(SENT)	320492.084	2251634.125	408.61	409.19	643.95	BR	628.0-678.0	632.0-672.0	4	SS
	ERM-9S(SENT)	320536.061	2251952.437	419.99	420.27	144.29	BR	121.0-152.0	125.0-145.0	4	SS
	ERM-9I(SENT)	320519.446	2251946.541	420.51	420.83	348.22	BR	302.0-352.0	310.0-350.0	4	SS
	ERM-9D(SENT)	320517.279	2251930.144	421.16	421.46	670.91	BR	625.0-677.0	630.0-670.0	4	SS

Note * The reference point for the top of casing measurements for the production wells is the top of a mounting bolt on the pump.

BLS = below land surface
MSL = Mean Sea Level
BR = Bedrock
OB = Overburden

Table K-2
Production Well Construction Details
Middletown Airfield NPL Site

Location of Well	Well I.D.	PA State Grid Coordinates Northing (Y)	Easting (X)	Elevation Top of Casing (MSL)	Borehole Diameter (in)	Well Depth (feet BLS)	OB/ BR Well	Casing Depth (feet BLS)	Open Borehole Interval (feet BLS)	Pump Depth (feet BLS)
Production Wells	HIA-1	315808.522	2249479.870	324.32	10	629	BR	104	104-629	250
	HIA-2	315899.836	2249167.950	325.92	10	450	BR	100	100-450	250
	HIA-3	315742.706	2249774.960	320.21	10	450	BR	100	100-450	250
	HIA-4	316121.998	2248940.480	325.05	10	140	BR	100	100-140	140
	HIA-5	316013.728	2249771.680	320.65	10	450	BR	100	100-450	140
	HIA-6	316334.212	2243025.610	296.15	NA	500	BR	200	200-500	180
	HIA-9	316001.759	2244243.550	309.32	10	450	BR	101	101-450	140
	HIA-11	316675.868	2244041.040	307.07	10	603	BR	75	75-603	250
	HIA-12	316756.938	2243381.870	301.00	10	603	BR	75	75-603	210
	HIA-13	316218.167	2246681.520	304.99	10	602	BR	75	75-602	350
	MID-04	320778.010	2252147.080	414.05	10	815	BR	50	50-815	400

Note * The reference point for the top of casing measurements for the HIA and MID production wells is the top of a mounting bolt on the pump.

BLS = Below land surface
MSL = Mean Sea Level
BR = Bedrock
OB = Overburden
NA = Not Available

K.2 SITE BACKGROUND

K.2.1 HIA WATER SYSTEM OPERATIONS

The HIA Water Department presently has 10 active production wells to supply water to the airport and adjacent industries and businesses. The active wells include HIA-1, 2, 3, 4, 5, 6, 9, 11, 12, and 13. An additional well, HIA-14, is used exclusively for heating and cooling purposes and is not connected into the water supply system. Figure K-3 shows the relative locations of the HIA production wells. Most of the HIA wells are cased to depths between 75 to 200 feet and are open hole from that depth to the total well depths between 450 to 800 feet.

The water system operates on an "as needed" basis. Typically no well is pumped continuously unless there is a greater than normal demand on the system. Water from the HIA production wells is blended together and treated by the HIA Water Department prior to distribution in the potable water system. Treatment includes water softening, air stripping and chlorination. The water treatment plant has two air strippers which operate in parallel with capacity of 2,100 gpm. The system has the flexibility to operate air strippers in series if concentration of contaminants exceeds normal levels. The average daily demand on the water supply system is 1.1 million gallons per day (MGD). The normal flow rate of the system ranges from 1,100 to 1,200 gpm. The system's fire requirements are 2,100 gpm.

The normal pumping configuration consists of four well, two wells serving as lead wells with two additional wells serving as first and second lag wells. The two lead wells operate together, the lag wells turn on when demand exceeds the amount supplied by the lead wells. Well HIA-13 is usually the lead pumping well, paired with one of the lower yielding wells (HIA-1, 2, 3, 4, 5, or 9) as the second lead well. Wells HIA-6, 11, or 12 typically serve as lag wells. Combined flow from the two lead wells is typically 650 - 700 gpm. There is a fairly consistent draw on the system 6 days a week because of industrial needs of Chloé Eichelberger textile manufacturer. Pumping rates generally decrease on Sundays when the manufacturing production is not operating.

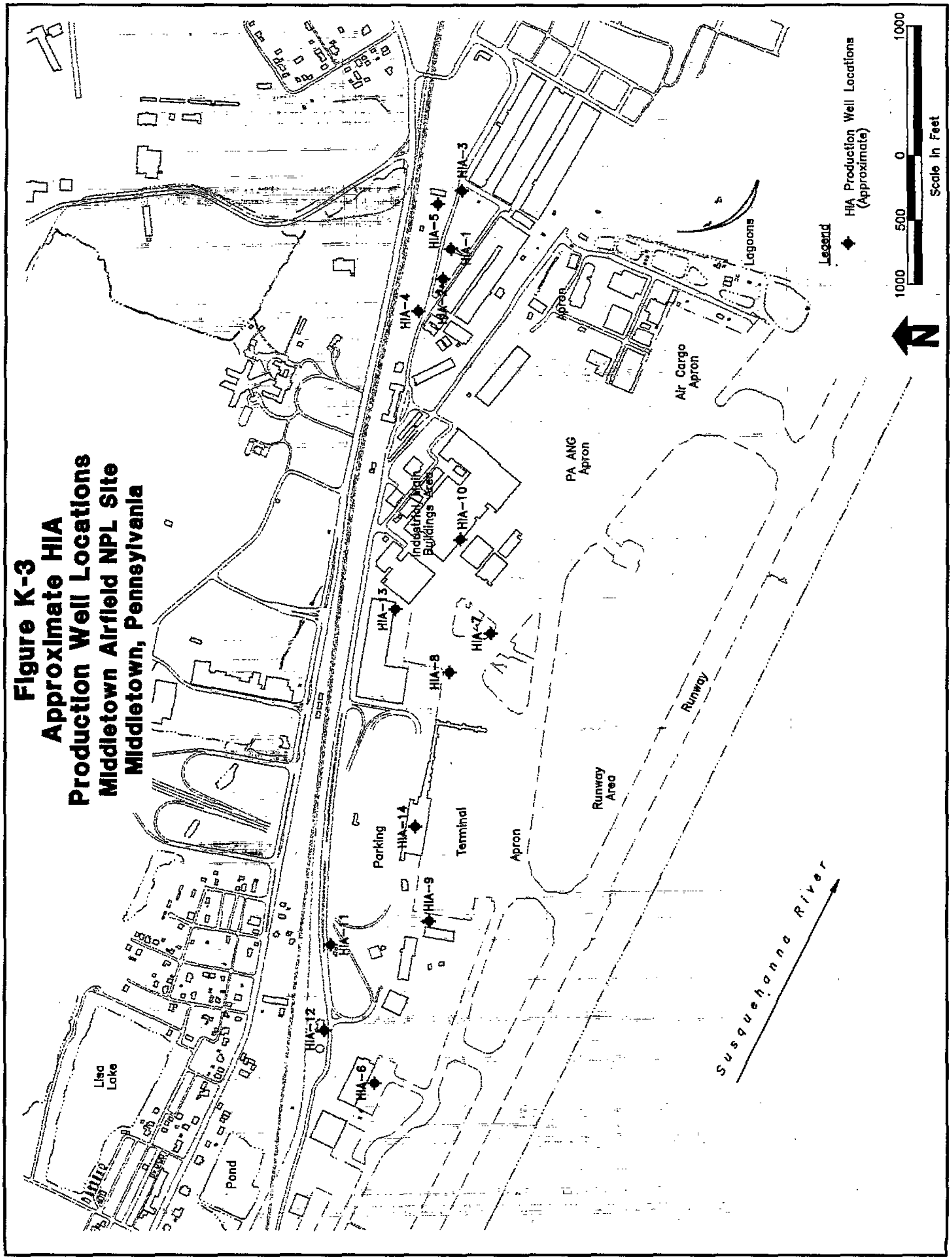


Figure K-3
Approximate HIA
Production Well Locations
Middletown Airfield NPL Site
Middletown, Pennsylvania

Several of the HIA production wells have historically shown elevated levels of volatile organic contamination. HIA-13 has historically had the highest contaminant concentration. Wells HIA-6 and HIA-12 have historically been free of contaminants of concern. Both wells HIA-6 and HIA-12 are located in the Western area near the HIA Water Treatment Plant.

Wells HIA-7, 8, 10, 15, 16, 17, and 18 are not in service. HIA-7 is located inside an active hangar underneath the concrete. HIA-8 is located on an active airport ramp and is inaccessible. HIA-10 has been capped. Wells HIA-15 and HIA-16, which are located in the northern portion of the property just outside the Fruehauf Company gate, were drilled but never put into service. Wells HIA-17 and HIA-18 are cased holes.

K.3 CAPTURE ZONE TESTS

Four aquifer tests were conducted, one in each of the Eastern, Central, and Western areas of the Site, and in the vicinity of the North Base Landfill. Constant-rate pumping tests were conducted on production wells HIA-2 (Eastern), and HIA-9 (Western), and recovery tests were conducted on production wells HIA-13 (Central) and MID-04.

These aquifer tests were performed to provide data on shallow, intermediate, and deep aquifer characteristics. Although unique conditions existed at each area, general aquifer test procedures were applied to all aquifer tests performed. A description of the general procedures for each aquifer test is presented below.

K.3.1 GENERAL TEST PROCEDURES

Each aquifer test was divided into three phases: a pre-test stabilization phase, the test phase and a recovery/restart phase. The tests were performed either as constant rate pumping tests in wells that are normally off, or as recovery tests in wells that are normally pumping. For the constant-rate pumping tests the phases consisted of the following:

- Pre-test stabilization phase where all the production wells in the vicinity of the test were taken off-line and shut down for at least 24 hours. This allowed the aquifer to achieve stable ground water conditions prior to the execution of the capture zone test. Electronic data recorders were installed in monitoring wells at the beginning of the pre-test phase to monitor the water levels throughout the aquifer test;
- Pumping phase where the selected production well was pumped continuously at a constant rate. Since the HIA Water Department could not handle the volume of water that was to be pumped during the tests, the water was discharged to the storm drain system which emptied into the Susquehanna River. The water from MID-04 was pumped into the Borough of Middletown's water system. The pumping phase of the testing lasted approximately 72 hours. Other production wells in the area remained off-line, if possible, through the duration of the test.

In addition to the electronically monitored wells, hand measurements were collected from select wells every 0.5 hour for the first 2 hours after the pump was turned on, every hour for the next 8 hours, and then every 8 hours for the remainder of the pumping phase. Hand measurements were collected periodically from the electronically monitored wells in order to validate the electronic data. Submergence depth readings of the other HIA production wells in the area of the pumped well were recorded from the bubbler panel in the control room at the HIA Water Department Treatment Plant.

- Recovery phase where the production well was shut down for approximately 72-hours to allow water levels to recover to pre-test conditions. The electronic data loggers remained in the wells to monitor the water level recovery, but no hand depth to water measurements were collected during this portion of the test. The primary purpose of the data collected during this phase was to backup the data collected during the pumping phase of the test in the event that the pumping phase data was lost or appeared unreliable.

The recovery-type aquifer tests conducted on wells HIA-13 and MID-04 were conducted in an almost identical manner as the constant-rate tests except that the pumping and recovery phases were reversed. The pre-test stabilization phase consisted of pumping the test well at a constant rate while monitoring the water levels in the surrounding wells. The test phase consisted of turning the well off and measuring the recovery rate in the surrounding wells at the same frequency described above for at least 72 hours. The third phase consisted of restarting the test well and maintaining a constant pumping rate for approximately 24 hours. Water levels in the capture zone well nests were electronically recorded during the restart phase.

K.3.2 *AMBIENT MONITORING*

Prior to conducting the capture zone tests at the Site, ambient monitoring of water levels in selected monitoring wells was performed. The purpose of the ambient monitoring was to obtain data on ambient water level fluctuations in the aquifers under normal conditions. The production wells were operated in their normal "on-demand" mode during the ambient monitoring period. Water level and barometric pressure data were collected at 15 minute intervals using electronic data recorders and pressure transducers. Recorder strip charts, and daily reports detailing the well configuration, total pumpage, and average pumping rate of each of the HIA production wells during the ambient monitoring period were obtained from the HIA Water Department.

The ambient monitoring of water levels at the Middletown Airfield Site were conducted from 27 July 1995 to 4 August 1995. Two wells in each of the four test areas were monitored as per the Work Plan. These wells include:

Eastern Area	GF-210, GF-310
Central Area	ERM-32I, ERM-32D
Western Area	GF-212, GF-312
North Base Landfill Area	ERM-13I, ERM-14I

Table K-3 presents the total daily pumpage of the HIA production wells for the ambient monitoring period. Precipitation records and barometric pressure data for this time period were obtained from the weather station at the HIA. A cumulative rainfall of 0.8 inches for the 6 hour measurement interval from 1245 to 1845 hours was recorded on 28 July 1995.

The ambient water level monitoring data was examined to determine whether the magnitude of ambient water level fluctuations could interfere with the analysis of data collected during the Capture Zone Tests. The ambient fluctuations in water levels, neglecting pumping impacts, was on the order of 0.5 feet. Separating responses to pumping of similar magnitude to the ambient fluctuation may be difficult. None of the wells exhibited a response to a precipitation event that occurred on 28 July 1996. This suggested that a rainfall event would not significantly impact the pumping tests. Finally, the wells included in the ambient monitoring program were considered background wells for each aquifer test. Although several of the background wells showed responses to pumping, the large responses suggested that ambient changes in water levels were much smaller than the response to pumping in many wells. Therefore correction for background fluctuations was not an issue in the data analysis.

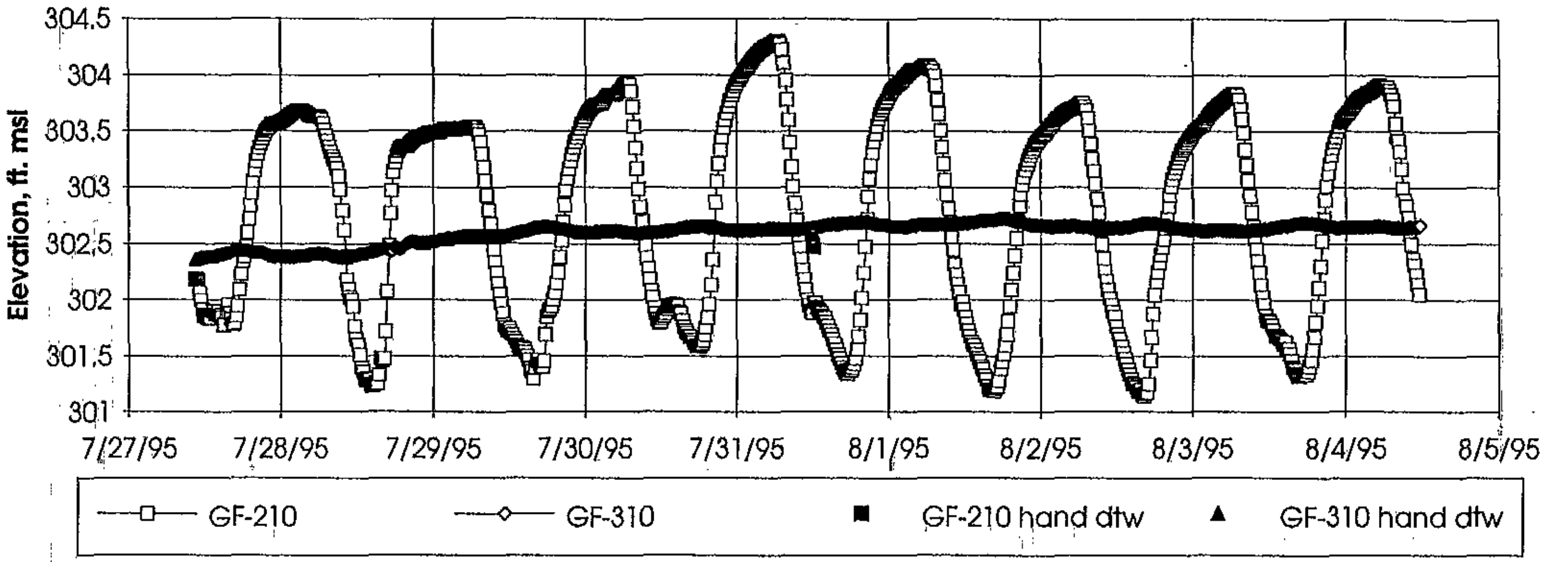
K.3.2.1 Eastern Area

Wells GF-210 and GF-310 were monitored in the Eastern Area. Figure K-4 is a graph of the ambient water level data and barometric pressure data for these wells.

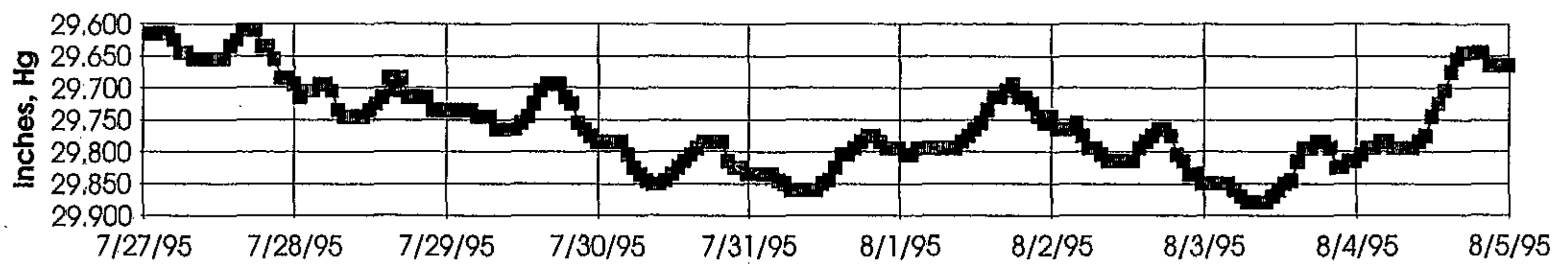
Table K-3
Operation of HIA Production Wells
During Ambient Monitoring
Middletown Airfield Site

Date	7/27/95	7/28/95	7/29/95	7/30/95	7/31/95	8/1/95	8/2/95	8/3/95	8/4/95
Well	**Total Daily Pumpage, gallons**								
HIA-1	0	0	0	13,200	182,400	178,800	188,400	176,400	160,800
HIA-2	0	0	0	0	0	0	0	0	0
HIA-3	0	0	0	0	0	0	0	0	0
HIA-4	0	0	0	0	0	0	0	0	0
HIA-5	0	0	0	0	0	0	0	0	0
HIA-6	0	0	0	44,200	358,100	328,400	357,000	345,300	324,600
HIA-9	164,500	188,300	100,300	22,900	0	0	0	0	0
HIA-11	361,000	787,000	257,000	50,000	0	0	0	0	0
HIA-12	7,800	7,200	9,100	0	8,000	6,900	9,200	18,900	0
HIA-13	339,200	390,600	218,300	90,500	356,900	355,700	361,600	344,500	329,800
HIA-14 (Non-potable, HVAC)	325,000	305,000	325,000	315,000	290,000	322,000	343,000	348,000	329,000

Figure K-4
Ambient Water Level Monitoring
Eastern Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



Barometric Pressure



- Well GF-210 varied approximately 3.5 feet per day in response to pumping. During the pumping test of HIA-2, production wells HIA-1, 3, 4, and 5 were shut down.
- Well GF-310 varied by approximately 0.3 feet in response to barometric pressure fluctuations over the week long monitoring period. This magnitude of change did not impact the reduction or evaluation of the data.

K.3.2.2 *Central Area*

Wells ERM-32I and ERM-32D were monitored in the Central Area. Figure K-5 depicts the responses of these wells.

- The observed water levels in wells ERM-32I and ERM-32D varied by less than 1 foot per day and 10 feet per day, respectively, in response to HIA-13 pumping. During the recovery test of HIA-13, this effect will be eliminated as production well HIA-13 will be shut off.

K.3.2.3 *Western Area*

Wells GF-212 and GF-312 were monitored in the Western Area. Figure K-6 depicts the responses of these wells.

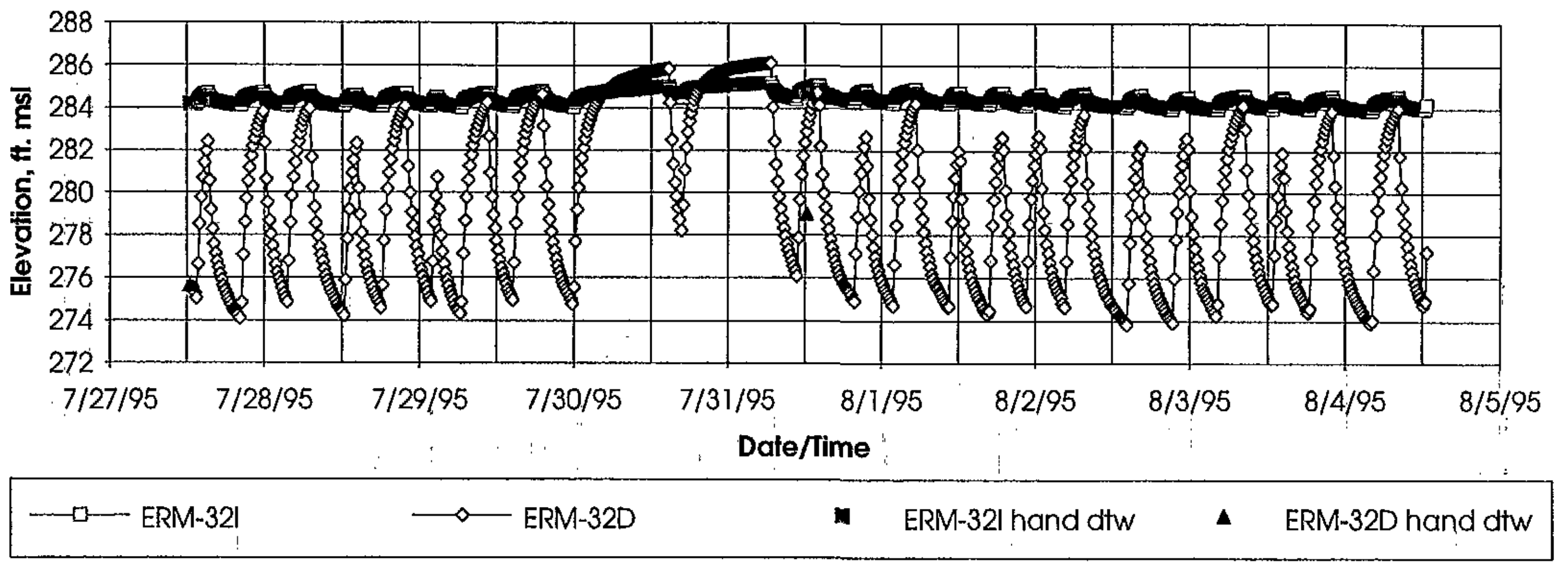
- Well GF-212 varied approximately 0.5 feet per day in response to pumping. Well GF-312 varied by approximately 1 to 2 feet per day.

K.3.2.4 *North Base Landfill Area*

Wells ERM-13I and ERM-14I were monitored in the North Base Landfill Area. Figure K-7 depicts the responses of these wells.

- Water levels in wells ERM-13I and ERM-14I varied by approximately 0.2 and 0.4 feet in response to barometric pressure fluctuations over the week long monitoring period. This magnitude of change should not impact the reduction or evaluation of the data. The Middletown production well MID-04, in the vicinity of these wells, pumps continuously and does not cycle on and off as do the HIA production wells located in the Industrial Area of the Site.

Figure K-5
Ambient Water Level Monitoring
Central Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



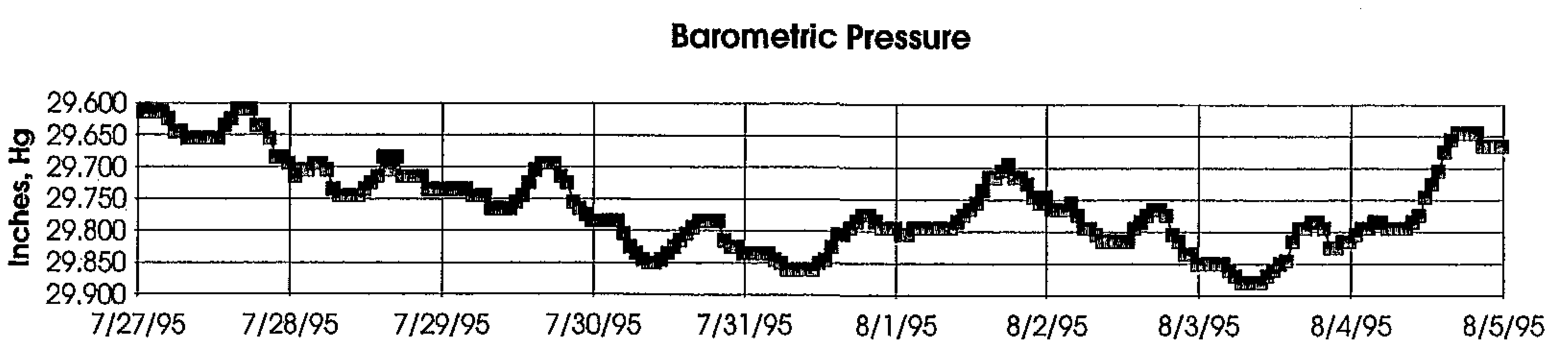
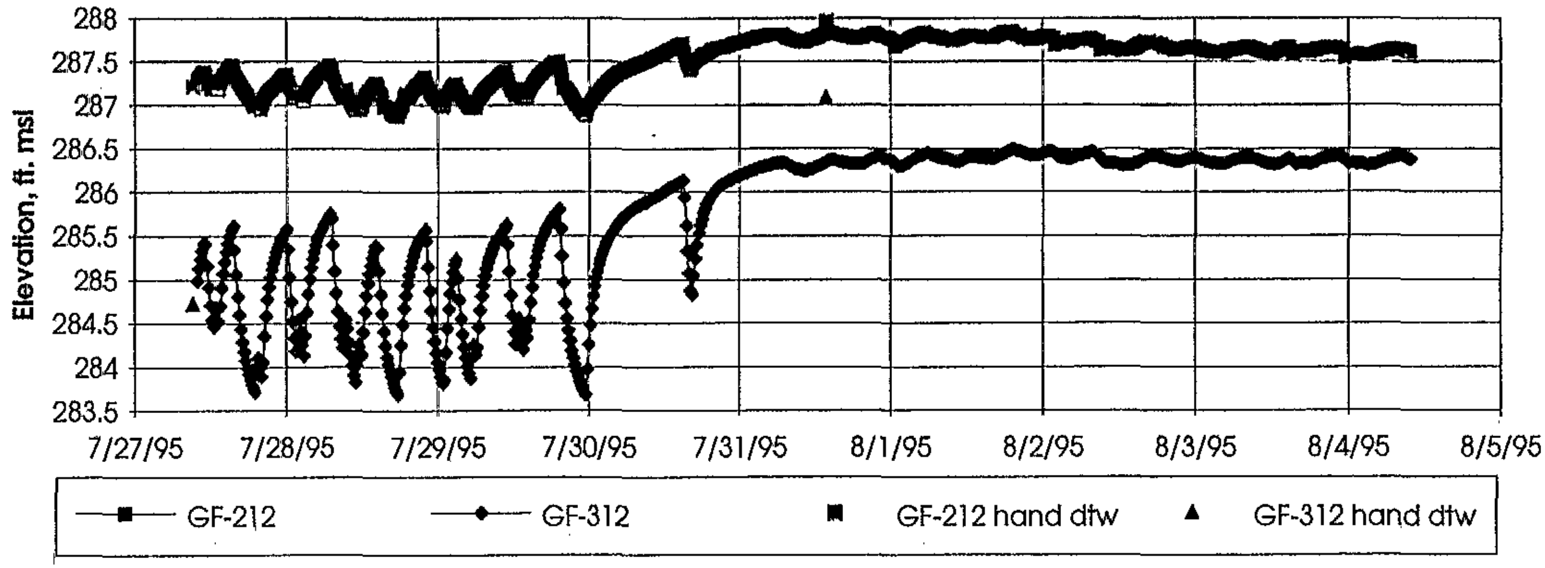


Figure K-6
Ambient Water Level Monitoring
Western Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



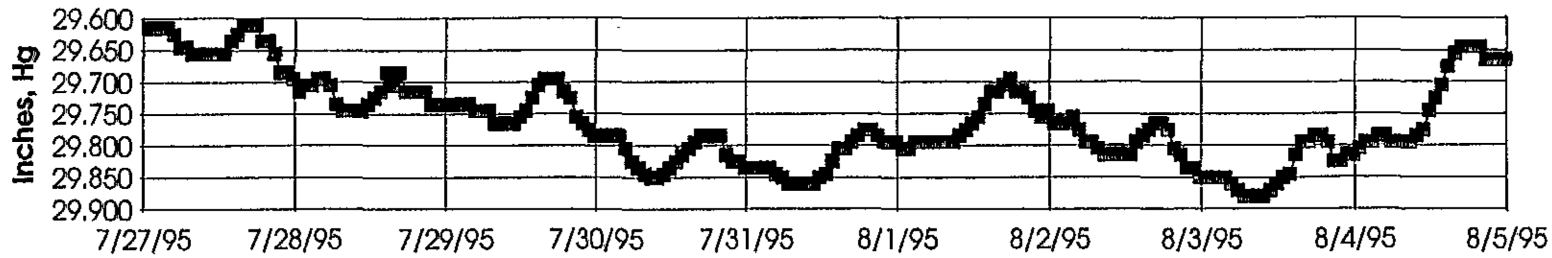
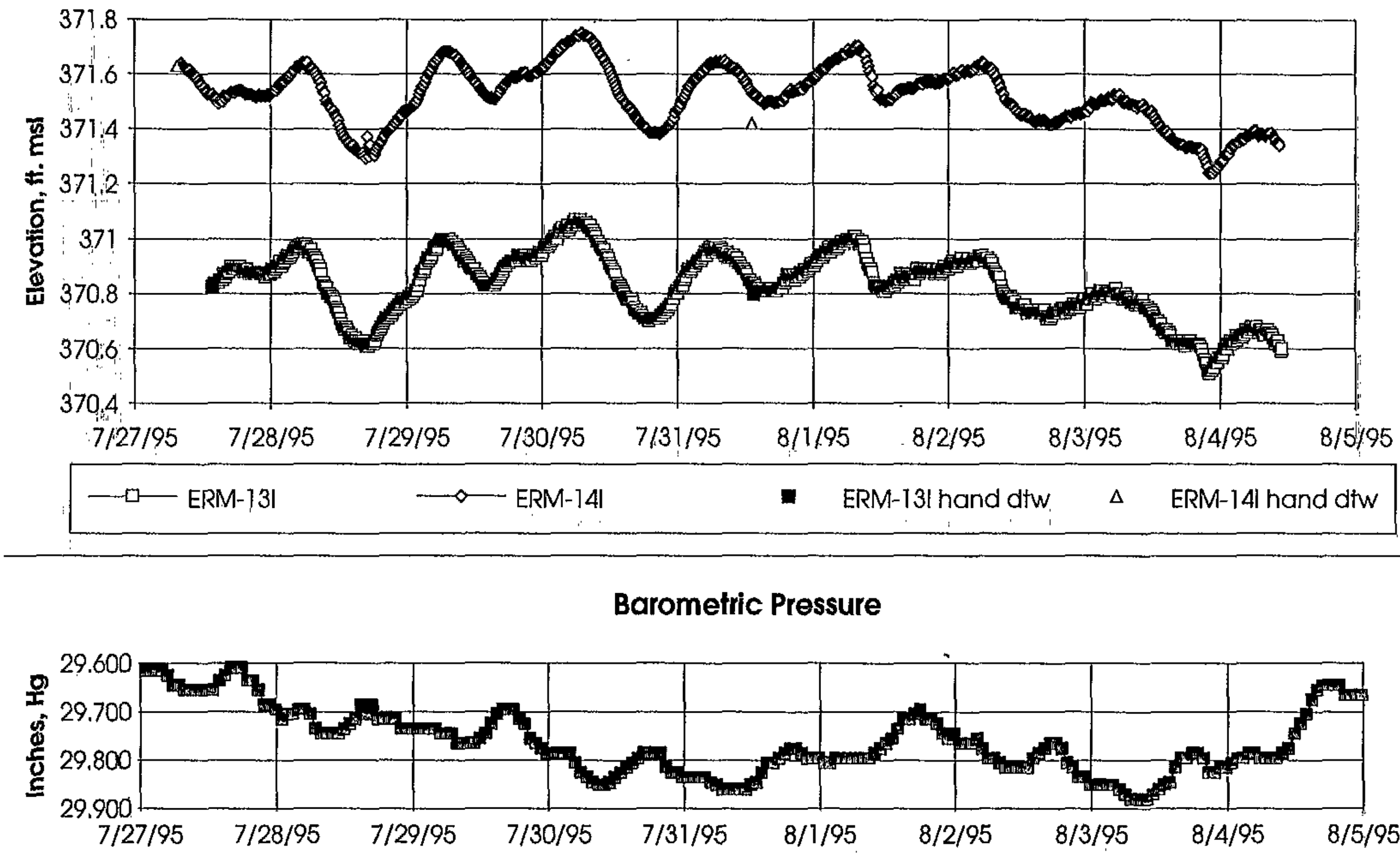


Figure K-7
Ambient Water Level Monitoring
North Base Landfill Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



K.3.3 *AQUIFER TEST*

K.3.3.1 *Eastern Area*

A constant-rate pumping test was conducted on well HIA-2 from 9:00 AM on 3 October 1995 to 10:00 AM on 6 October 1995. The well was pumped at a rate of 265 gallons per minute (gpm) for approximately 73 hours. Water levels in 16 wells, including HIA-2, were monitored during the HIA-2 pumping test. Figure K-8 illustrates the location of the wells monitored during the capture zone test. Electronic data recorders were installed in wells ERM-25S, ERM-25I, ERM-25D, ERM-26S, ERM-26I, ERM-26D, GF-311, GF-310, and GF-210 prior to the pre-test phase to monitor the water levels in these wells for the duration of the test. Well GF-211 was scheduled to be monitored however the well was dry at the time of the test. Hand measurements were collected from wells ERM-28S and GF-227, and bubbler readings were collected from production wells HIA-1, HIA-2, HIA-3, HIA-4, and HIA-5. Hand measurements and bubbler readings were recorded only during the pumping phase of the test.

The HIA wells used to supply water to the distribution system during the testing of HIA-2 were configured in the following manner:

- Lead Wells: HIA-13 (Central) and HIA-9 (Western)
- First Lag Well: HIA-11(Western)
- Second Lag: HIA-6 (Western)

K.3.3.2 *Central Area*

A recovery test was conducted on well HIA-13 from 7:55 AM on 19 March 1996 to 7:05 AM on 22 March 1996. The well was pumped directly into the storm drain system at a rate of 430 gallons per minute (gpm) for approximately 25 hours prior to the recovery portion of the test. Water levels in 20 wells were monitored during the HIA-13 recovery test. Figure K-9 illustrates the location of the wells monitored during the capture zone test. Electronic data recorders were installed in wells ERM-23S, ERM-23I, ERM-23D, ERM-24S, ERM-24I, ERM-24D, ERM-32I, ERM-32D, and RFW-3 prior to the pre-test phase to monitor the water levels in these wells for the duration of the test. Hand measurements were collected from wells ERM-3S, ERM-4S, ERM-5S, ERM-6S, ERM-10I, ERM-27S, GF-218, GF-318, GF-219, GF-220, and RFW-4. Bubbler readings were collected from well HIA-

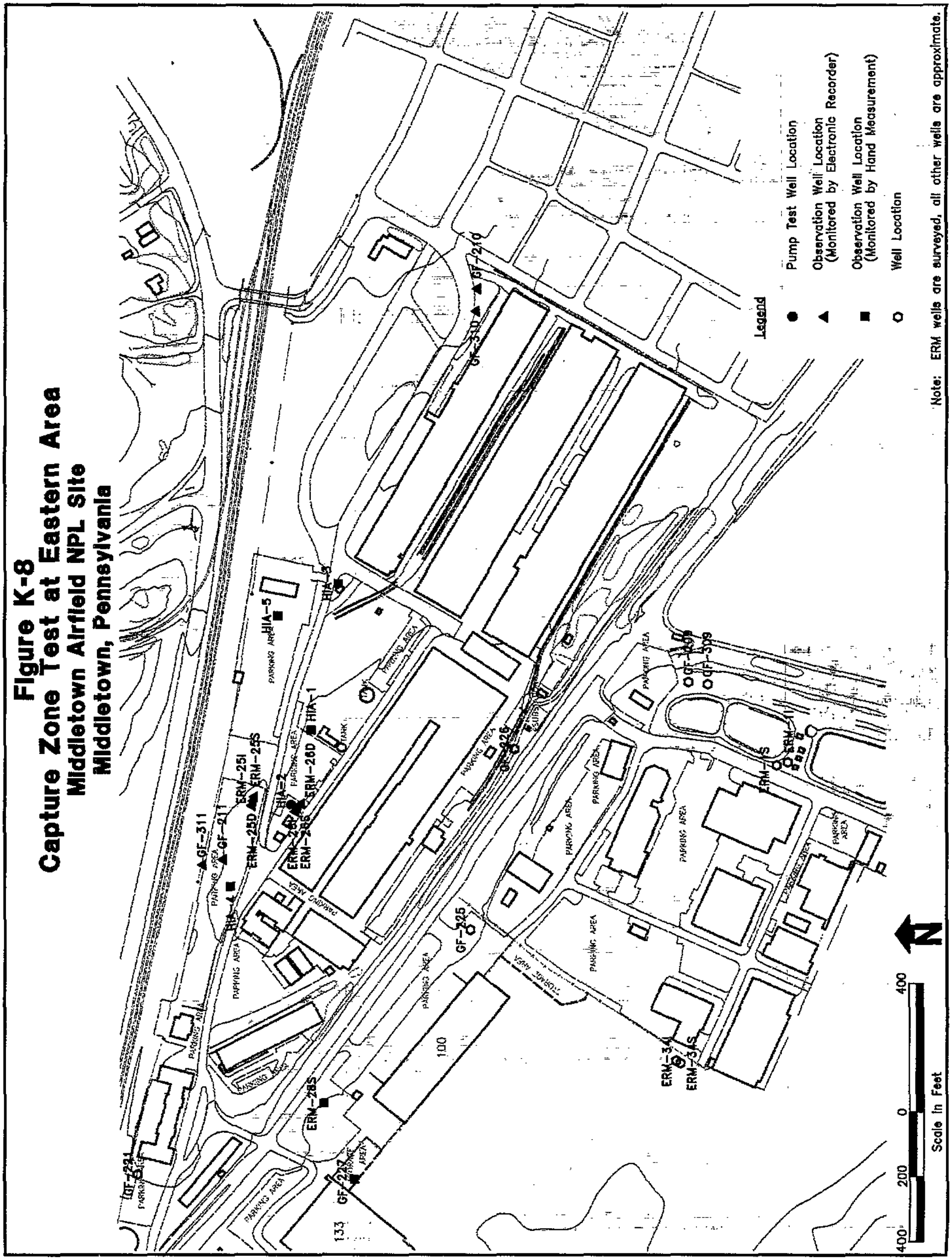
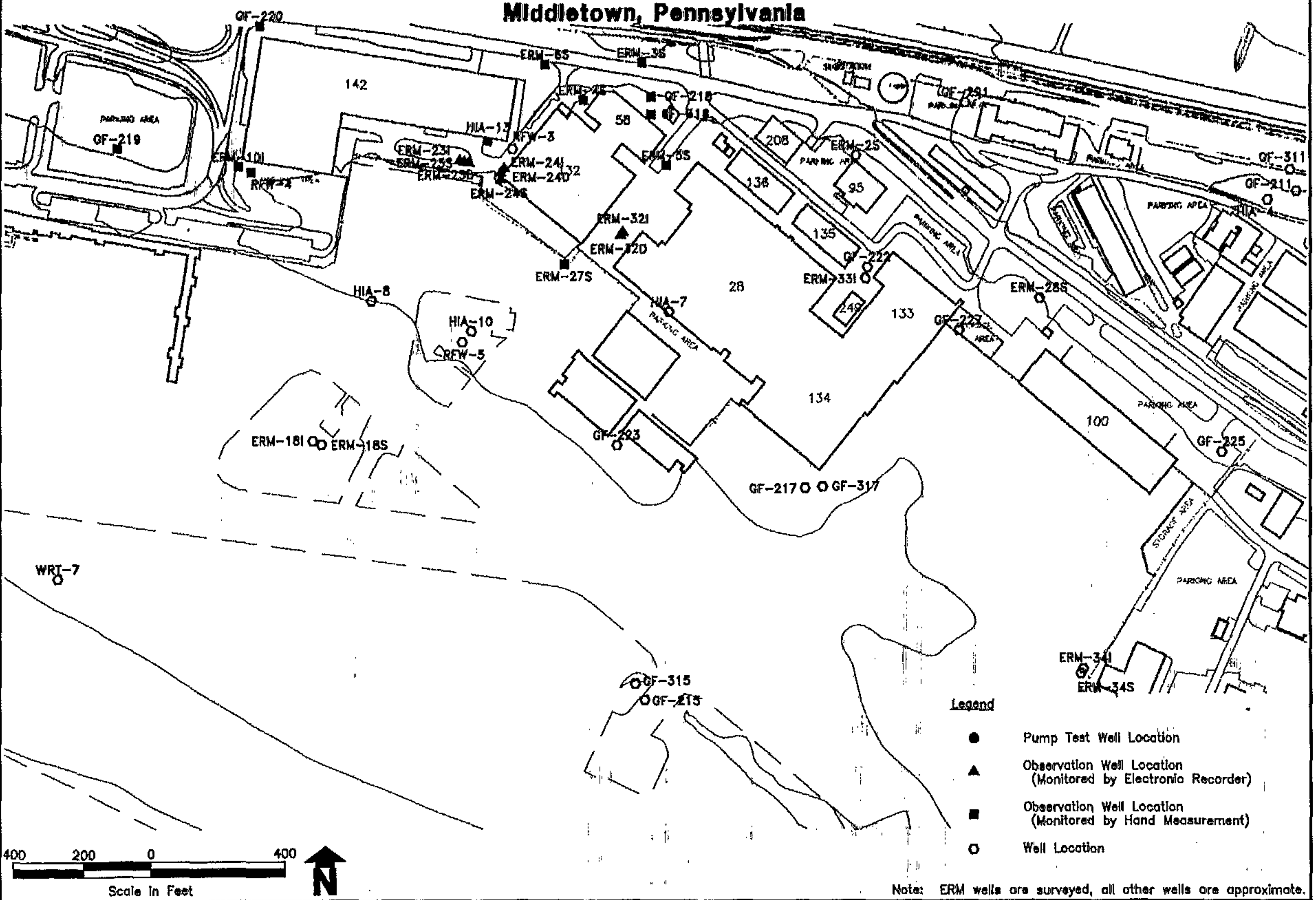


Figure K-8
Capture Zone Test at Eastern Area
Middletown Airfield NPL Site
Middletown, Pennsylvania

Figure K-9
Capture Zone Test at Central Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



13 at least once per day. Hand measurements and bubbler readings were recorded only during the pumping phase of the test.

The HIA wells used to supply water to the distribution system during the testing of HIA-13 were configured in the following manner:

- Lead Well: HIA- 12 (Western)
- First Lag Well: HIA-11 (Western)
- Second Lag: HIA-1 (Eastern)

K.3.3.3 *Western Area*

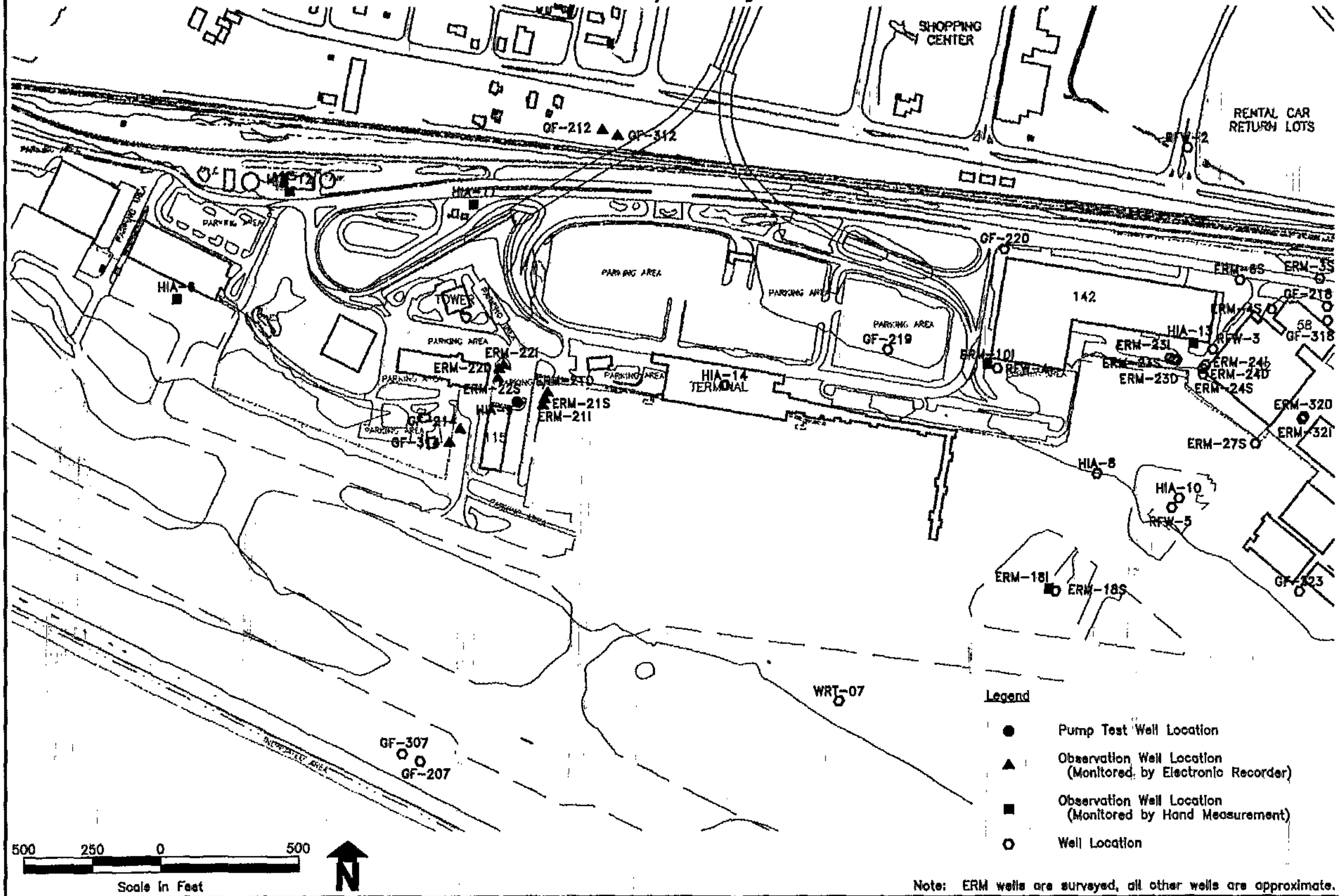
A constant-rate pumping test was conducted on well HIA-9 from 10:00 AM on 26 September 1995 to 11:00 AM on 29 September 1995. The well was pumped at a rate of 205 gallons per minute (gpm) for approximately 73 hours. Water levels in 16 wells, including HIA-9, were monitored during the HIA-9 pumping test. Figure K-10 illustrates the location of the wells monitored during the capture zone test. Electronic data recorders were installed in wells ERM-21S, ERM-21I, ERM-21D, ERM-22S, ERM-22I, ERM-22D, GF-314, GF-312, and GF-212 prior to the pre-test phase to monitor the water levels in these wells for the duration of the test. Well GF-214 was scheduled to be monitored however this well was dry at the time of the test. An electronic data logger was added to well ERM-10I prior to the pumping phase to monitor the water levels in this well during the pumping of well HIA-9 and the recovery phase of the test. Due to a data logger malfunction in well ERM-22S, water levels in this well were measured by hand. Bubbler readings were collected from wells HIA-6, HIA-9, HIA-11, HIA-12, and HIA-13. Hand measurements and bubbler readings were recorded only during the pumping phase of the test.

The HIA wells used to supply water to the distribution system during the testing of HIA-9 were configured in the following manner:

- Lead Wells: HIA-13 (Central) and HIA-1 (Eastern)
- First Lag Well: HIA-12 (Western)
- Second Lag Well: HIA-6 (Western)

For the first 100 minutes the lead wells were HIA-12 and HIA-6, with HIA-1 and HIA-2 serving as the first and second lag wells. As a result of HIA-9 pumping continuously, the water level in HIA-6 dropped causing the low-level alarm to go off. At that time, HIA-6 was turned off and HIA-

Figure K-10
Capture Zone Test at Western Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



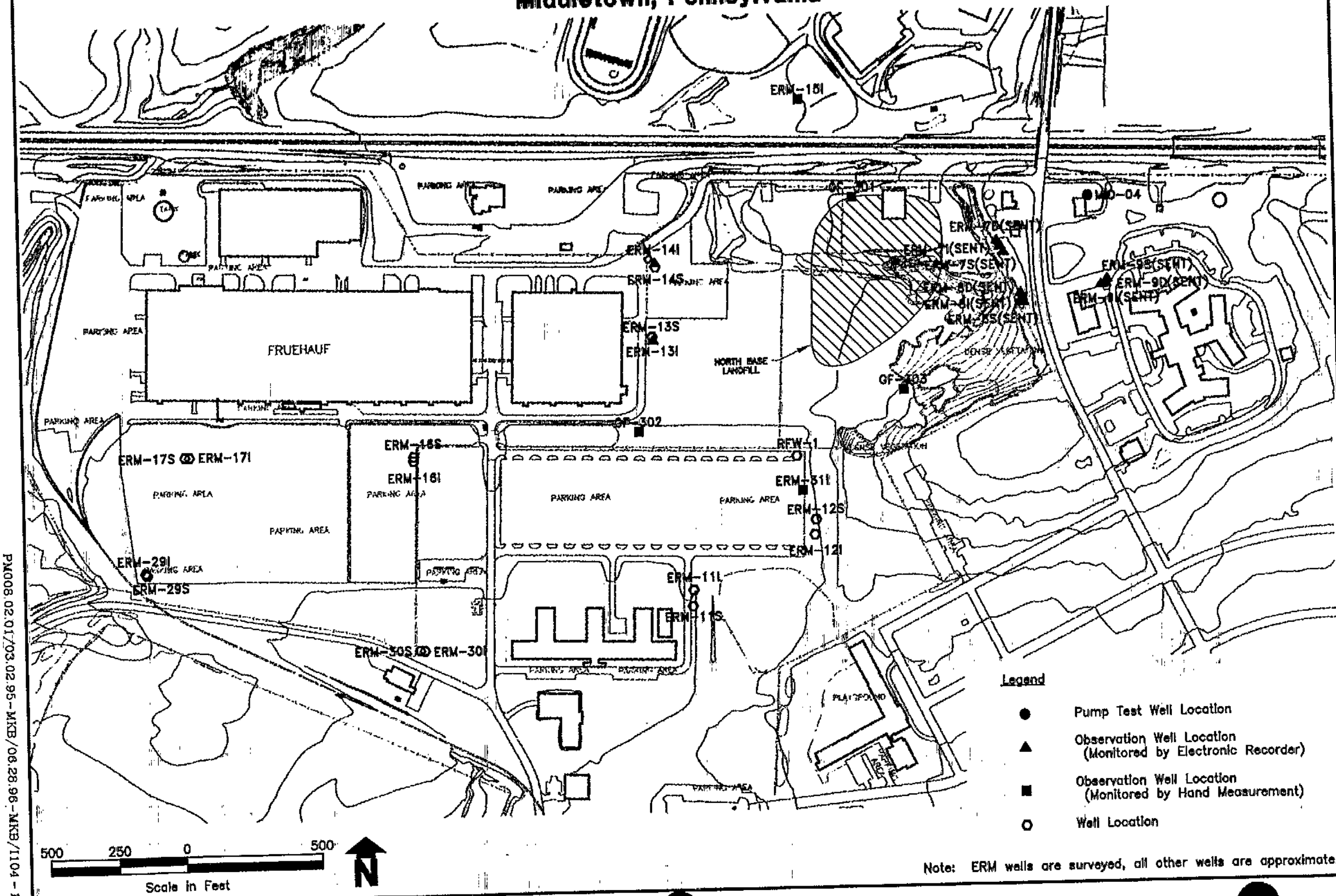
13 was put on-line. A second change to the well configuration was required as a result of HIA-9 pumping continuously, which activated the treatment system causing the blower and chlorinator to run even though no water was entering the treatment system. In order to resolve this problem, the well configuration was changed again on 27 September 1995 at 0752 hours (1342 minutes into pumping portion of the test) to HIA-1 and HIA-13 as lead wells and HIA-12 as 1st lag and HIA-6 as 2nd lag.

K.3.3.4 North Base Landfill Area

A recovery test was conducted on well MID-04 from 9:00 AM on 10 October 1995 to 10:00 AM on 13 October 1995. The well was constantly pumped at a rate of 80 gallons per minute (gpm) by the Middletown Borough Authority. Water levels in 18 wells were monitored during the MID-04 recovery test. Figure K-11 illustrates the location of the wells monitored during the capture zone test. Electronic data recorders were installed in wells ERM-7S, ERM-7I, ERM-7D, ERM-8S, ERM-8I, ERM-8D, ERM-9S, ERM-9I, ERM-9D, ERM-13S, ERM-13I, ERM-14S, ERM-14I prior to the pre-test phase to monitor the water levels in these wells for the duration of the test. Hand measurements were collected from wells ERM-15I, ERM-31I, GF-301, GF-302, and GF-303. Bubbler readings from the HIA wells were not recorded since well MID-04 was far enough away not to be impacted by the pumping of these wells. The bubbler on MID-04 was not operating properly at the time of the recovery test. Hand measurements were recorded only during the recovery phase of the test.

It was anticipated that the normal operation of the HIA production wells would not impact the testing of MID-04. Therefore no alteration to the HIA well pumping schedule was required during the testing of MID-04.

Figure K-11
Capture Zone Test at North Base Landfill Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



K.4 *PUMPING TEST ANALYSIS*

The data for each test was plotted and analyzed to determine in-situ aquifer parameters. For each well monitored during the capture zone tests, the following data plots were prepared and are attached in Attachments K.1 and K.2.

- Arithmetic graphs of time versus ground water elevation, and
- Semi-logarithmic graphs of time versus drawdown.

K.4.1 *General Observations*

Based on a review of the data, the following observations were made:

- Partial penetration effects were observed in the drawdown response at the well nests installed near the pumping wells. For example, at the ERM-9 sentinel well nest, the shallow, intermediate, and deep wells recovered approximately 0.7, 5.5, and 63 feet respectively in response to the recovery of production well MID-04. Attempts to identify vertical versus horizontal hydraulic conductivity however, were complicated by the nature of the bedrock aquifer. In general, the production wells have open hole intervals from 51 to 815 feet but only draw water from limited portions of the borehole.
- Anisotropy was expected to manifest itself as an elliptical cone of depression. This was not observed. The response to pumping in wells along strike was similar to the response observed in wells up and down dip from the pumping well. Thus, anisotropic conditions were not observed in the test results. This may be the result of the spacing and depth of the observation wells such that they do not intersect the fractures being affected by pumping or near vertical fractures in the pumping well which were not intersected in the observation well.
- Dual porosity effects (similar to water table delayed yield response) were observed in some data. However, the data analysis did not pursue determination of a fracture storage coefficient versus a matrix storage coefficient. Aquifer transmissivity, not storage coefficient, was required to perform the steady-state modeling. Only the later time matrix storage coefficients are presented in the data analysis results.

- Leveling off of the drawdown curve was observed in several wells near the end of the test. This may be due to communication with the river (a recharge boundary), or the cessation of pumping in a well somewhere in the vicinity. This condition did not generally interfere with the data evaluation. Analysis of distance to a recharge boundary was not performed as the effects were not conclusively related to a recharge boundary nor were there sufficient observations to identify the location of such a boundary.

K.4.2 Data Analysis

Based on the general observations, the Cooper-Jacob method was selected as the best method for initial data analysis. This method is preferable to other analysis methods as it evaluates the aquifer transmissivity based on a rate of drawdown (slope of a line) versus the absolute drawdown.

The transmissivity was calculated from the pumping rate and the slope of the semi-logarithmic graph of time versus drawdown using the following relationship:

$$T = 264Q/\Delta s$$

where

T = transmissivity, gpd/ft
Q = pumping rate, gpm
Δs = change in drawdown for one log cycle of time.

The Cooper-Jacob method is also useful for anisotropic aquifers. The slope of the straight-line portion of the graph should be the same in all directions and a transmissivity determined from that slope would represent the effective transmissivity:

$$T_{eff} = (T_{major} * T_{minor})^{1/2}$$

Determination of an anisotropy ratio could, if present, be determined from the elliptical shape of the cone of depression. Again, the cones of depression appear to be circular rather than elliptical suggesting isotropic conditions. No directional flow preferences were observed from the capture zone test data. As mentioned previously, this may be the result of the well spacing or the near vertical fractures within the bedrock aquifer.

The Cooper-Jacob method allows transmissivity to be calculated without corrections for partial penetration effects or anisotropy. Arithmetic data plots for individual wells are presented in Attachment K.1. Semi-log data plots are presented in Attachment K.2. In addition, for each pumping test, those wells responding to pumping were plotted on one Cooper-Jacob graph. Figures K-12 through K-15 illustrate the Cooper-Jacob method for each capture zone test. These graphs present the observed drawdown (or recovery for a recovery test) versus the elapsed time divided by the square of the distance from the observation well to the pumping well (t/r^2). The t/r^2 transformation should result in the graphs from different wells overlying each other. Failure of the graphs to overlie is related to anisotropic effects, partial penetration effects, or aquifer heterogeneities. Table K-4 presents the drawdown (or recovery) observed in each well during the capture zone tests.

Figure K-12 is a Cooper-Jacob plot, which illustrates the drawdown in Sentinel wells ERM-7I & D, ERM-8I & D, and ERM-9I & D during the MID-04 test. The paired intermediate and deep wells are at approximately the same orientation to MID-04 and the same distance. Thus, the absolute drawdown in the intermediate and deep wells should be identical. The difference in the drawdown and time it occurs, is the result of partial penetration effects. However, all three wells exhibit a similar rate of drawdown (slope of the straight line portion of the curve). The slope can be used to determine aquifer transmissivity without any partial penetration corrections. Analysis by methods using absolute drawdown (Theis, 1935) would require partial penetration corrections.

Both anisotropy and partial penetration effects were evaluated after the initial transmissivity calculation. The effects of horizontal anisotropy (along geologic strike versus along dip) were not observed in the data. Anisotropy and partial penetration effects were evaluated using a computer program ANIAQX from HydraLogic. By defining the construction details for the pumping and observation wells, ANIAQX can correct for partial penetration and determine the ratio of horizontal to vertical hydraulic conductivity. ANIAQX will also identify horizontal anisotropy, if present. Data from each test were input into ANIAQX for analysis. ANIAQX evaluates several wells at a time (i.e. intermediate wells from each capture zone well nest). However, the program would not achieve an acceptable solution. This is likely the result of heterogeneous aquifer conditions typical of bedrock aquifers.

The representative transmissivity value determined for each test area is as follows:

Figure K-12
Sentinel Wells Near MID-04
Aquifer Recovery Test
Middletown Airfield NPL Site
Middletown, Pennsylvania

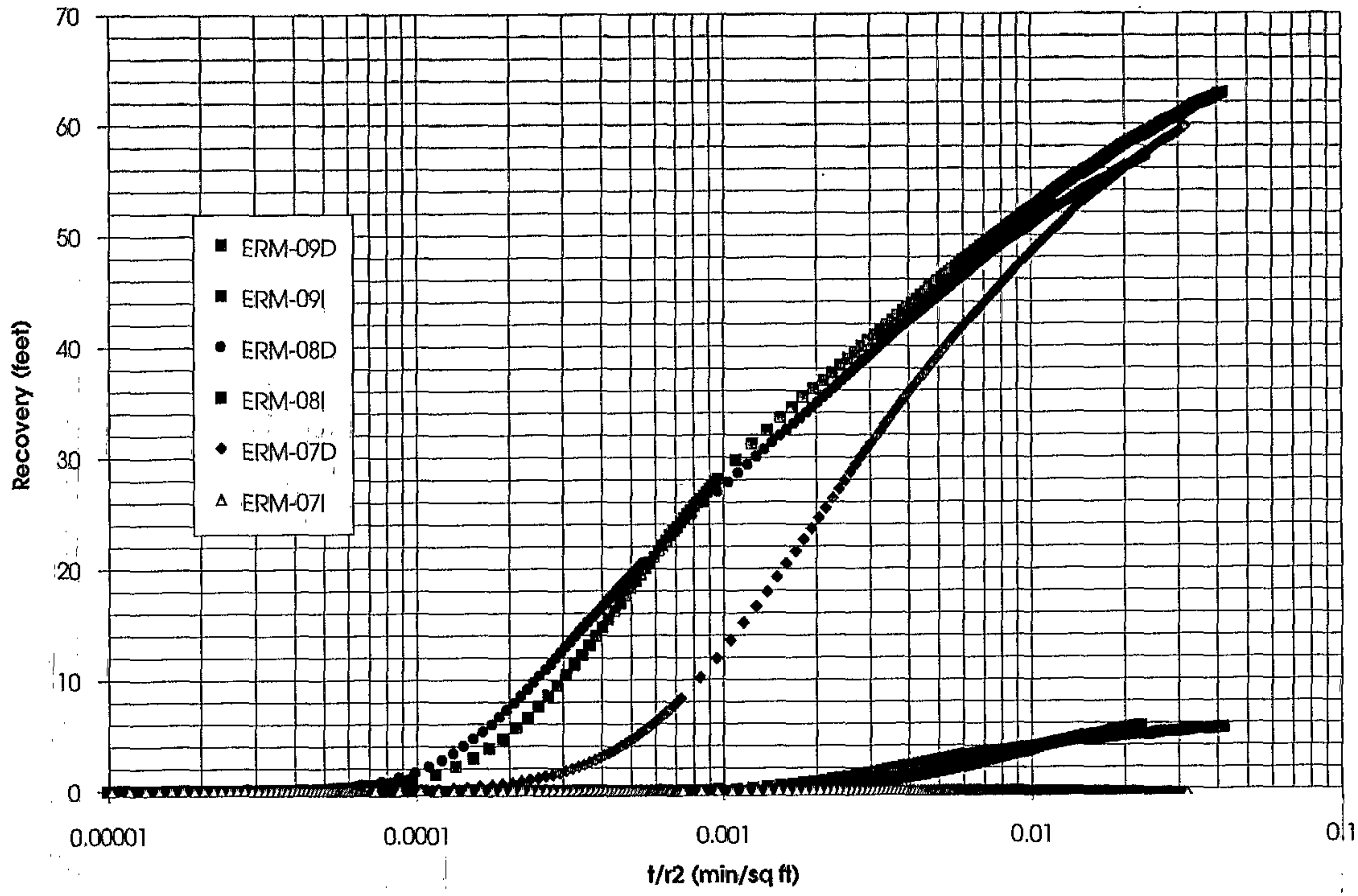


Figure K-13
Capture Zone Wells Near HIA-2
Aquifer Pumping Test
Middletown Airfield NPL Site
Middletown, Pennsylvania

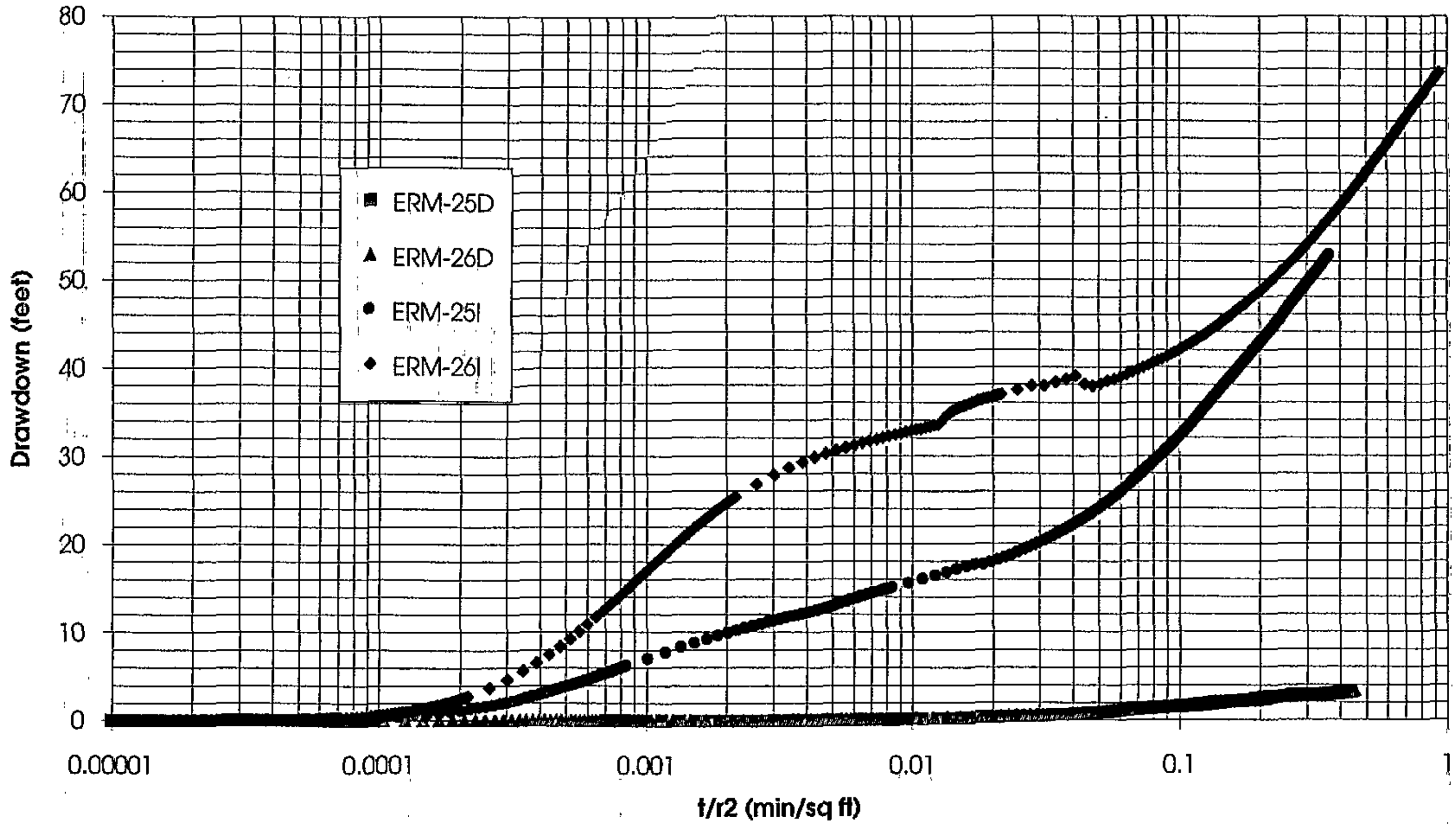


Figure K-14
Capture Zone Wells Near HIA-13
Aquifer Recovery Test
Middletown Airfield NPL Site
Middletown, Pennsylvania

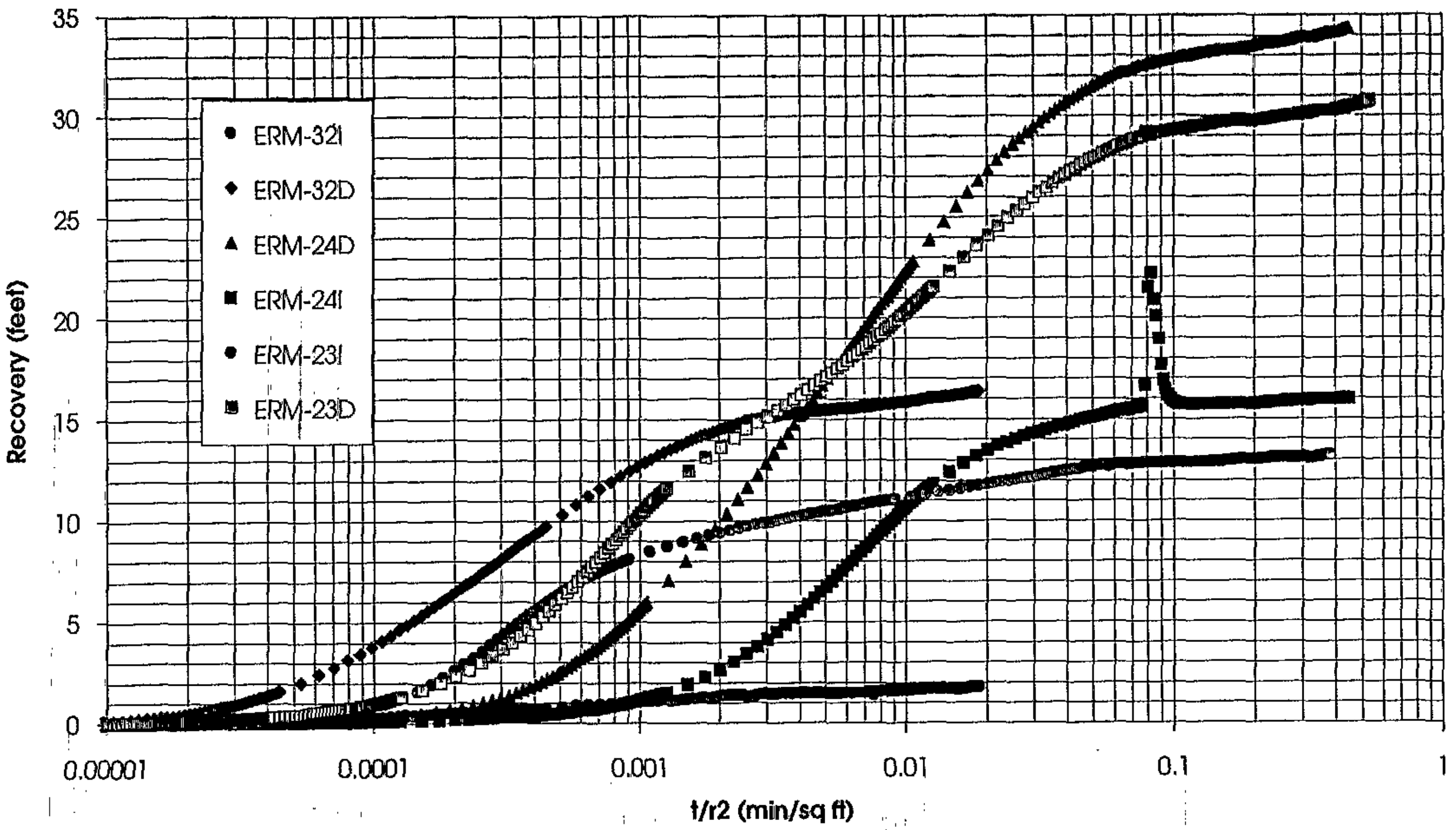


Figure K-15
Capture Zone Wells Near HIA-9
Aquifer Pumping Test
Middletown Airfield NPL Site
Middletown, Pennsylvania

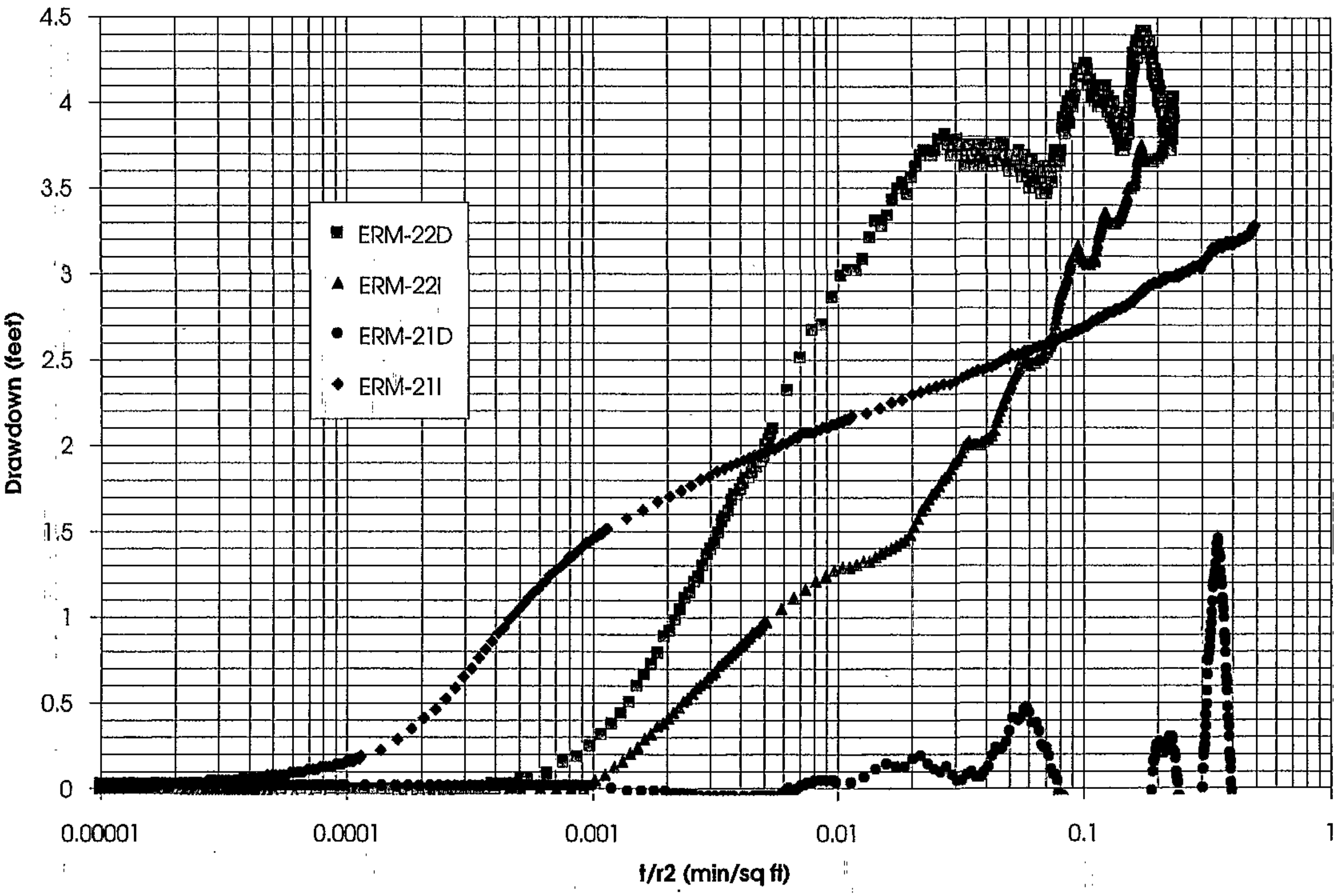


Table K-4
Observed Capture Zone Test Drawdown
Middletown Airfield Site

Eastern Area HIA-2		Central Area HIA-13		Western Area HIA-9		NBL Area MID-04	
Well	Drawdown, ft.	Well	Recovery, ft.	Well	Drawdown, ft.	Well	Recovery, ft.
ERM-25S	3.85	ERM-23S	0.64	ERM-21S	4.25	ERM-7S	0
ERM-25I	52.5	ERM-23I	13.00	ERM-21I	3.29	ERM-7I	0
ERM-25D	3.35	ERM-23D	31.00	ERM-21D	---	ERM-7D	60.5
ERM-26S	4.5	ERM-24S	0.68	ERM-22S	2.2	ERM-8S	0.23
ERM-26I	74.8	ERM-24I	16.00	ERM-22I	4	ERM-8I	5.85
ERM-26D	3.45	ERM-24D	34.00	ERM-22D	4.08	ERM-8D	57
GF-311	2.65	ERM-32I	1.70	GF-214	Dry	ERM-9S	0.7
ERM-28S	0.15	ERM-32D	17.00	GF-314	2.5	ERM-9I	5.7
GF-227	0.24	RFW-3	0.32	ERM-9	86	ERM-9D	62
HIA-1	14.6	GF-218	0.80	ERM-150	150		
HIA-2	144.6	GF-318	3.00				
HIA-3	1.4						
HIA-4	15.5						
HIA-5	4.2						

Eastern Area	HIA-2	230 ft^2/day
Central Area	HIA-13	1,100 ft^2/day
Western Area	HIA-9	3,200 ft^2/day
NBL Area	MID-04	130 ft^2/day

These transmissivity values were used in the capture zone analysis, presented in Section K.5.

K.4.2.1 *Results for MID-04*

Figure K-12 presents the observed drawdown in the Sentinel wells near MID-04. No significant drawdown was observed in other wells during the test. The deep wells ERM-7D, ERM-8D, and ERM-9D each exhibit a drawdown of approximately 60 feet and the curves are falling on top of each other toward the later part of the test (after approximately 1 day). The overlying curves indicates that, on the scale that the test was performed, there are no observable horizontal anisotropic effects near MID-04. Also observable on the figure is the significant difference between the drawdown in the deep and the intermediate wells. This is typical of partial penetration effects where the pumping well is open at an elevation similar to the deep observation well. MID-04 is open from 51 to 815 feet below grade, however the screened interval of both the intermediate and deep sentinel wells fall within this range. Based on well construction, similar drawdowns in the intermediate and deep sentinel wells would be expected. Inputting the well construction information into the ANIAQX software, the program could not converge to a solution for these pumping test data.

It appears that MID-04 is drawing water from a higher permeability zone at the elevation of the deep sentinel wells. This is a heterogeneous aquifer condition which is not compatible with pumping test analysis models. An aquifer transmissivity was determined for the MID-04 area using the Cooper-Jacob graphs for the deep sentinel wells. An average value of 130 ft^2/day was determined. The Cooper Jacob curves, Figure K-12, are gradually flattening out, suggesting effects of higher transmissivity areas of the aquifer or recharge boundaries influencing the drawdown.

K.4.2.2 *Results for HIA-2*

Figure K-13 presents the observed drawdown in wells ERM-25I, ERM-25D, ERM-26I, and ERM-26D near production well HIA-2. As discussed previously, the graph presents drawdown versus t/r^2 and the data plots should overly each other in a homogeneous, isotropic aquifer with a fully penetrating pumping well.

From Figure K-14 and Table K-4, it can be seen that the intermediate level wells respond much more to pumping than the deep or shallow wells. This response demonstrated that the majority of the water for HIA-2 is being provided by an interval of the bedrock at or near the elevation of the intermediate wells. Evaluating the curves for ERM-25D and ERM-26D, there are two straight line portions of the curves. The later time data were considered representative of the aquifer. The possibility of the latter time data representing an impermeable hydraulic boundary was considered, however, the change in slope of the curves from the midsection of the curve (slope ~8 feet/log cycle) to the end of the curve (~41 feet/log cycle) is too great to represent a hydraulic boundary. A single impermeable wall boundary would cause a change in slope by a factor of 2 (i.e., the 8 feet/log cycle would become 16 feet/log cycle). A change this large would also require a completely impermeable boundary, there is no evidence that such a boundary is present. To achieve the change in slope from 8 feet/log cycle to 41 feet/log cycle would require very low permeability boundaries almost surrounding HIA-2. Thus, the later time data were considered representative of the aquifer in the vicinity of HIA-2. Using the slope of 41 feet per log cycle, the aquifer transmissivity in the area of HIA-2 is estimated to be 230 ft^2/day (1,700 gpd/ft).

The curves for ERM-25D and ERM-26D exhibit similar slopes, however, if the curve for ERM-25I was extended it could be seen that an equivalent drawdown in ERM-26I would occur slightly earlier than in ERM-25I. This suggests a very slight anisotropy with the aquifer transmissivity in the direction of ERM-26I, along strike, approximately 20% greater than the transmissivity in the direction of dip.

K.4.2.3 Results for HIA-13

Figure K-14 presents the observed drawdown in wells ERM-23I, ERM-23D, ERM-24I, ERM-24D, ERM-32I, and ERM-32D near production well HIA-13. The greatest drawdown was observed in the deep wells closest to HIA-13, ERM-24D and ERM-23D. Contrary to the expected response of greater drawdown in the direction of bedrock strike compared to the direction normal to strike; ERM-24D, located normal to strike, drewdown more than ERM-23D which is located along strike. The significance of this observation is two-fold. First, there is no evidence of the expected anisotropic conditions. Second, as observed in the other tests, the response to pumping is influenced by heterogeneous conditions.

Using the graphs shown on Figure K-15, an aquifer transmissivity value was calculated for the area of HIA-13. The straight line portion of the curves analyzed on Figure K-15 was the mid portion, the steepest line. This selection was made by eliminating the alternative straight line portion of the curve, the late time data. Matching the late time data yields a very large transmissivity, approximately 8,000 ft^2/day (60,000 gpd/ft). However, if this value was representative of the aquifer, the specific capacity of the HIA-13, calculated from the following relationship, would be approximately 30 gpm/ft.

$$Q/s = T/2000 \qquad \text{(Driscoll, 1986)}$$

where

Q/s = specific capacity (gpm/ft)
T = transmissivity (gpd/ft)

Based on this relationship. the drawdown in well HIA-13 would be approximately 14 feet at the pumping test rate of 430 gpm. This drawdown is less than observed in ERM-24D which is located approximately 100 feet from HIA-13. Thus, the transmissivity calculated from the later time data is not a reasonable value. The flattening of the drawdown curve in the late time data is likely related to the influence of the Susquehanna River acting as an aquifer recharge boundary.

The middle sections of the Cooper-Jacob curves were analyzed for aquifer transmissivity. The average of the transmissivity values using ERM-23D, ERM-24I, ERM-24D, ERM-32I, and ERM-32D (ERM-23I was not included due to limited data in the straight-line mid-section of the graph) was 1,100 ft^2/day (8,100 gpd/ft).

K.4.2.4 Results for HIA-9

Figure K-15 presents the observed drawdown in wells ERM-21I, ERM-21D, ERM-22I, and ERM-22D near production well HIA-09. The later time data appears to be influenced by cyclic pumping in the area, the pumping source was not identified but could possibly be the HVAC well HIA-14. The observation wells near HIA-09 exhibited significantly less drawdown than was observed in the other pumping tests. This demonstrates a significantly greater aquifer transmissivity in this area. The curves for ERM-22I and ERM-22D exhibit similar slopes and the drawdown in ERM-22I lags the drawdown in ERM-22D, consistent with partial penetration effects. An aquifer transmissivity of 3,200 ft^2/day was determined for ERM-22I and ERM-22D. In contrast, the drawdown observed in ERM-21I and ERM-21D are significantly different. ERM-21D has no measurable response to pumping HIA-09, although another well appears to be influencing its water levels. ERM-21I exhibits a "nice" pump test curve.

However, the late time slope is significantly less than observed at ERM-22I and ERM-22D. As discussed previously, the Cooper-Jacob drawdown plots for a pumping test in an anisotropic aquifer should provide the same slope, i.e. transmissivity in all directions. Thus, the difference in slope between ERM-21I and ERM-22I does not indicate anisotropy. Also, ERM-21I, located along bedrock strike, has less drawdown than ERM-22I, located down dip. It was anticipated prior to the test that the aquifer would be more conductive along strike. If this were true, ERM-21I should have drawn down more than ERM-22I. The difference in response between the wells in the ERM-21 and ERM-22 well nests is the result of heterogeneities in the aquifer and not due to anisotropic conditions.

K.4.2.5 Comparison of Results with 1961 USGS Report

In 1961, the USGS published a report, Ground-Water Resources of Olmsted Air Force Base, Middletown, Pennsylvania. This report summarized the results of pumping tests performed in 1959 on wells Da-78 in the NBL Area (referred to as the Warehouse Area in the USGS Report), Da-81 (HIA-2) in the Eastern Area, Da-92 (HIA-13) in the Central Area, and Da-90 (HIA-11) in the Western Area.

Well Da-78 in the NBL Area (Fruehauf and Gulf Oil Corporation) was pumped at 25 gpm for approximately 30 hours. The USGS evaluation of this pumping test yielded a transmissivity of 170 ft^2/day (1,250 gpd/ft). This value compares well with the 130 ft^2/day transmissivity value for the MID-04 pumping test.

The USGS divided the Main Base into the same areas designated for the SSI, the Eastern, Central, and Western Areas.

In the Eastern Area, well Da-81 (HIA-2) was pumped at 200 gpm for 859 minutes. Wells HIA-1, HIA-3, and HIA-4 were used as observation wells. The following table summarizes the USGS results in the Eastern Area:

Well	distance from HIA-2 (ft)	drawdown (ft)	T (ft^2/day)	T (gpd/ft)
HIA-1 (Da-80)	325	5.6	3,900	29,000
HIA-2 (Da-81)	0.5	90		
HIA-3 (Da-82)	325	0.6	25,000	
HIA-4 (Da-83)	630	6.5		

In the Central Area, HIA-13 (Da-92) was pumped at 575 gpm for 195 minutes. Well HIA-8 was used as an observation well. The following table summarizes the USGS results in the Central Area:

Well	distance from HIA-13 (ft)	drawdown (ft)	T (ft^2/day)	T (gpd/ft)
HIA-13 (Da-92)	0.5	>90		
HIA-8 (Da-87)	480	5.5	1,600	12,000

In the Western Area, HIA-11 (Da-90) was pumped at 700 gpm for 315 minutes. Wells HIA-9, and HIA-12 were used as observation wells. The following table summarizes the USGS results in the Western Area:

Well	distance from HIA-11 (ft)	drawdown (ft)	T (ft^2/day)	T (gpd/ft)
HIA-9 (Da-88)	680	0.7	35,000	260,000
HIA-11 (Da-90)	0.5	45		
HIA-12 (Da-91)	650	4.6	7,400	55,000

The transmissivity values calculated by the USGS for the Industrial Area of the Site were significantly greater than those determined during ERM's testing. There are several explanations, the most important being the duration of the testing. The USGS tests were significantly shorter than ERM's tests. When testing a heterogeneous aquifer such as the one which exists at the Site, the early portions of the test are impacted greatly by heterogeneous conditions in the vicinity of the pumping well. A longer duration test, as performed by ERM, provides better data for evaluation of the aquifer properties on a scale more representative of the well capture zones. The USGS tests also identified deviations from the Theis pump test model as impermeable or recharge boundaries. These deviations occurred early in the test and were more likely the result of dual porosity effects typically observed in bedrock aquifers, or a transition from the local heterogeneous aquifer conditions to larger scale aquifer properties.

In summary, the aquifer tests performed for this SSI were longer duration tests than those performed by the USGS in 1959. The SSI test results are more representative of the aquifer on the scale of interest, the capture zone of the HIA production wells. It should be recognized however, that the SSI tests and the USGS tests were influenced by heterogeneous conditions which cannot be quantified using aquifer pumping tests and that the aquifer properties generated by testing in this aquifer will be rough estimates of the aquifer properties.

K.4.2.6 *Summary*

The results of the pumping tests provided good estimates of the aquifer transmissivity in the Industrial Area and the North Base Landfill Area. Due to heterogeneous conditions, aquifer storage coefficients and horizontal to vertical anisotropy could not be determined. The lack of storage coefficients will not interfere with quantitative analysis of the aquifer since the capture zone evaluations to be performed are based on steady-state models and do not require storage coefficient as a model input parameter. The lack of a horizontal to vertical anisotropy measurement will complicate future 3-dimensional modeling as this ratio is important to evaluating the 3-dimensional influence of the pumping wells.

The pumping test results demonstrate that the transmissivity of the bedrock aquifer is increasing moving from the North Base Landfill Area toward the Industrial Area and from east to west. The Western Area exhibited an aquifer transmissivity approximately 25 times greater than the North Base Landfill Area. This is likely the result of increased fracturing in the bedrock in the Western Area.

During the planning of the pumping test, it was anticipated that anisotropic conditions would be observed, i.e. that a greater drawdown would be observed in the direction of bedrock strike (approximately N 43 E) verses the direction of dip. Observation wells were installed along strike and along dip to monitor this effect. However, anisotropic conditions were not indicated by the aquifer testing. The lack of evidence is attributed to heterogeneous conditions within the bedrock aquifer which may have masked anisotropic effects if they exist.

On a regional scale, anisotropic conditions may effect ground water flow, however, the pumping tests performed could not identify these effects. The HIA-2 test results suggested that some anisotropy may exist in the Eastern Area with an anisotropy ratio of approximately 1.2 : 1. However, test data from the Central Area (HIA-13) indicated that the transmissivity in the direction normal to strike was greater than along strike (ERM-24D drewdown more than ERM-23D), exactly the opposite of what was expected.

K.5 CAPTURE ZONE ANALYSIS

This section presents the capture zone analysis. The objective of this analysis was to determine the capture zones of HIA production wells, HIA-1 through HIA-14 and the Middletown Borough Wells, MID-01 through MID-05, for different pumping scenarios. Determination of the capture zones is useful for evaluating the potential impact of site contamination on these wells.

Since the quantity of ground water withdrawal in this area is a significant portion of the total available water resources within the watershed and given that there are multiple pumping wells, the conventional analytical method could not adequately determine the capture zones of these production wells. A more advanced regional ground water modeling method was used to determine these capture zones. The TWODAN™ model employed in this analysis is similar to WhAEM™ which was developed by the USEPA for well head protection.

K.5.1 CONCEPTUAL MODEL

The first step in developing the ground water flow model was to construct a conceptual model. Regional and site-specific geologic, hydrogeologic, and climatic information were analyzed, generalized, and simplified to create the conceptual model.

The conceptual model for the regional aquifer that surrounds the Middletown Airfield was based on the following:

1. The modeling region encompasses the site area and the surrounding watersheds. It covers an area of approximately 20,000 feet by 20,000 feet. Within this region, the largest water table variation is approximately 150 feet (280 to 430 feet AMSL). The ratio between the largest water table variation to the area extent is less than 1 percent. The regional ground water flow is approximately two-dimensional and can be simulated by a two-dimensional ground water flow model for the purpose of capture zone determination.

2. Based on published geologic data, the regional aquifer (Gettysburg Formation) within the modeled area was developed under a similar

geological setting and experienced similar weathering and erosion conditions. As a result, the aquifer has generally similar hydraulic characteristics on the regional scale, and it is reasonable to assume a relatively uniform aquifer transmissivity for the entire region, except for the Industrial Area of the Site and the Susquehanna River, where alluvial sediment and secondary bedrock porosity produce a higher aquifer transmissivity. Transmissivity values in the Industrial Area of the Site generally increase from east to west. The model simulates this variation in transmissivity as derived from the capture zone tests (discussed in Section K.4).

3. The predominant source of ground water is infiltration from precipitation. Ground water generally flows toward surface water bodies, such as streams, ponds, and rivers, which have measurable surface water elevations. These surface water levels and infiltration rates control the elevation of the ground water table. On the regional scale, it is reasonable to assume that the infiltration rate is relatively uniform over the entire area.

4. The capture zone tests conducted at the Site found that the aquifer transmissivity is relatively consistent in different orientations, thus the model assumes isotropic conditions.

The conceptual regional ground water flow model for the Middletown Airfield Site was constructed as a two-dimensional isotropic aquifer that is recharged by uniform areal infiltration and that discharges to and is constrained by surface water features with constant surface water levels. The flood plain along the Susquehanna River has a higher aquifer transmissivity than the upland area of the regional model. The model was based on average annual conditions, and all input parameters and output results represent annual average values.

K.5.2 *MODEL SELECTION*

The ground water model TWODAN™, developed by Dr. C. Fitts, was selected for this modeling effort. TWODAN is an analytic element model that is based on the theory of the "Analytic Element Method" described by Strack (1989). The analytic element model was originally developed by Dr. O. Strack for regional ground water flow modeling. There are several models commercially available that are based on the analytic element method. These include QuickFlow™ by Geraghty and Miller, Inc., WhAEM™ by the USEPA and Strack, TWODAN by Fitts, GFlow™ by Dr.

H. Haitjema, and SLAEM™ and MLAEM™ by Strack. Analytic element models have been applied by the industry and regulatory agencies to environmental sites since the mid 1980s and have gained popularity and recognition due to the speed of model development and revisions.

The analytic element model is able to provide accurate and continuous solutions over an infinite flow domain in two dimensions. The model incorporates site-specific information obtained from the pumping tests, such as inhomogeniety in hydraulic conductivity and aquifer thickness. It is also capable of simulating ground water recovery systems such as wells, trenches, and slurry walls.

K.5.3 *MODEL SETUP AND INPUT PARAMETERS*

The TWODAN model of the Site included the following analytic elements. The surface water streams were simulated by constant-head linesinks in the model. The production wells were simulated by discharge-specified wells. The higher transmissivity areas were simulated as heterogeneity features. The regional infiltration was simulated by the circular recharge feature.

The surface water discharge control points for the regional model were obtained from USGS quadrangle maps. The drainage basins surrounding the site area were included in the development of the regional model. The actual model covers an approximate area of 20,000 feet by 20,000 feet.

K.5.3.1 *Model Input Parameters*

Transmissivity values were obtained from pumping test results. The production wells HIA-2 and MID-04 yielded aquifer transmissivities of 130 to 230 square feet per day, that reflect the Gettysburg Formation, whereas HIA-9 and HIA-13 yielded aquifer transmissivities of 3,200 to 1,000 square feet per day, that reflect the Susquehanna River channel. The regional aquifer transmissivity in the model was assigned to 230 square feet per day. A heterogeneity element with a transmissivity value of 3,200 square feet per day was placed along the Susquehanna River channel to account for the higher transmissivity of river channel sediments.

The reasonable range of the annual average areal infiltration was estimated based on a water budget that accounted for precipitation, surface runoff, evapotranspiration, and infiltration. The average annual precipitation for the Harrisburg area is approximately 44 inches per year (Chow, 1964). Normal annual runoff for the region is approximately 20 inches per year (Linsley, 1979). An estimate of annual average evapotranspiration was determined from climatological data to be approximately 12 inches per year (Linsley, 1979). Based on a regional water balance, the annual average infiltration rate is approximately 12 inches per year. The reasonable range of the annual infiltration rate was determined as 6 to 18 inches per year, roughly 50% off the estimated average value.

During model simulation of the well capture zones, the pumping rates of HIA production wells and Middletown Borough wells were based on the annual average pumping rates. Table K-5 presents the annual average pumping rates of the HIA production wells for 1990 through 1995. Since the pumping configuration of the HIA production wells varies, the average over the 5 year period was used as a representative annual average. The Middletown production wells MID-01, MID-02, MID-03, MID-04, and MID-05 operate at relatively consistent rates. Therefore the pumping rates of the Middletown Borough wells were based on the annual average rate in 1990 (GeoServices Ltd., 1992). The model input parameters and the average pumping rates for all the production wells are presented in Table K-6.

K.5.4 MODEL CALIBRATION

The regional ground water flow model simulates ground water flow from the point of infiltration to the point of discharge to surrounding surface water bodies. The natural water table profile is approximately a parabolic curve with the apex at the center of the watershed. Once the aquifer transmissivity and surrounding surface water levels are determined, the water table profile rises or falls as the assigned regional infiltration rate is increased or decreased. The model calibration process was accomplished by adjusting the infiltration rate until the simulated water table elevations match the known (measured) elevations. The calibration criteria were established as:

1. the relative average difference of modeled and measured water tables should be less than 10%; and
2. the calibrated infiltration rate should be within the estimated reasonable range.

Table K-5
HIA Production Well Data
Middletown Airfield NPL Site

Well	Average Gallons per Day						
	1990*	1991	1992	1993	1994	1995	5-year avg
HIA-1	21,405.5	63,759	41,942	36,351	64,256	49,658	46,229
HIA-2	40,346.8	79,205	72,380	67,255	72,474	67,598	66,543
HIA-3	12,157	5,926	11,889	835	0	73	5,147
HIA-4	556.2	504	56	75	731	80	334
HIA-5	15,816.7	28,942	34,120	23,578	13,289	731	19,413
HIA-6	116,405.5	92,479	108,228	100,187	51,164	115,441	97,317
HIA-9	26,457.5	21,153	12	28,741	10,833	24,565	18,627
HIA-11	77,515.1	96,984	164,967	171,521	124,252	114,795	125,006
HIA-12	139,279.5	131,293	145,758	108,575	129,420	168,390	137,119
HIA-13	323,202.5	335,877	247,792	258,500	313,991	197,645	279,501
HIA-14	230,843.8	282,781	218,661	182,551	201,074	236,088	225,333

Note: 1990 data for partial year. WTP on-line May 1990.

Well	Average Gallons per Minute						
	1990*	1991	1992	1993	1994	1995	5-year avg
HIA-1	14.9	44.3	29.1	25.2	44.6	34.5	32.1
HIA-2	28.0	55.0	50.3	46.7	50.3	46.9	46.2
HIA-3	8.4	4.1	8.3	0.6	0.0	0.1	3.6
HIA-4	0.4	0.4	0.0	0.1	0.5	0.1	0.2
HIA-5	11.0	20.1	23.7	16.4	9.2	0.5	13.5
HIA-6	80.8	64.2	75.2	69.6	35.5	80.2	67.6
HIA-9	18.4	14.7	0.0	20.0	7.5	17.1	12.9
HIA-11	53.8	67.4	114.6	119.1	86.3	79.7	86.8
HIA-12	96.7	91.2	101.2	75.4	89.9	116.9	95.2
HIA-13	224.4	233.2	172.1	179.5	218.0	137.3	194.1
HIA-14	160.3	196.4	151.8	126.8	139.6	164.0	156.5

Note: 1990 data for partial year. WTP on-line May 1990.

Table K-6
Model Input Parameters
Middletown Airfield NPL Site

Input Parameter	Input Value	Source
Aquifer Transmissivity:		
Gettysburg Formation	230 ft2/day	ERM Capture Zone Test
North Base Landfill Area (MID-04)	130 ft2/day	ERM Capture Zone Test
Eastern Area (HIA-2)	230 ft2/day	ERM Capture Zone Test
Central Area (HIA-13)	1,000 ft2/day	ERM Capture Zone Test
Western Area (HIA-9)	3,200 ft2/day	ERM Capture Zone Test
Susquehanna River Channel	3,200 ft2/day	ERM Capture Zone Test
Aquifer Porosity	5%	Freeze, 1979
Average Pumping Rate:	gpm	
HIA-1	35	HIA Water Plant Report
HIA-2	46.2	HIA Water Plant Report
HIA-3	0	HIA Water Plant Report
HIA-4	0	HIA Water Plant Report
HIA-5	14.4	HIA Water Plant Report
HIA-6	75	HIA Water Plant Report
HIA-7	Inactive	HIA Water Plant Report
HIA-8	Inactive	HIA Water Plant Report
HIA-9	0	HIA Water Plant Report
HIA-10	Inactive	HIA Water Plant Report
HIA-11	90	HIA Water Plant Report
HIA-12	96	HIA Water Plant Report
HIA-13	195	HIA Water Plant Report
HIA-14 (HVAC)	160	HIA Water Plant Report
MID-01	295	GeoServices, Ltd.
MID-02	214	GeoServices, Ltd.
MID-03	67	GeoServices, Ltd.
MID-04	89	GeoServices, Ltd.
MID-05	167	GeoServices, Ltd.
MID-06	Inactive	

The model was calibrated to simulate the water level conditions observed in the SSI. Water level measurements collected on 8 May 1995 were used to represent calibrated conditions. The configuration of the HIA production wells on 8 May 1995 was simulated in addition to the pumping of all 5 Middletown Borough wells. The average daily pumping rate for this date were used in the model simulation. The active HIA production wells included HIA-1 (107 gpm), HIA-6 (282 gpm), HIA-12 (41 gpm) HIA-13 (243 gpm), and HIA-14 (185 gpm). Model calibration was performed by adjusting the hydraulic parameters of the aquifer, such as hydraulic conductivity and the recharge rate, in order to achieve a relative fit to observed conditions.

Figure K-16 presents simulated ground water contours for the Middletown Airfield Site based on the calibrated ground water flow model. The figure illustrates the change in hydraulic gradient between the regional Gettysburg Formation and the Susquehanna River channel. This gradient change is a direct result of the difference in aquifer transmissivites between these two formations.

Pumping from the production wells causes a departure from 2-dimensional flow conditions in the vicinity of the pumping wells, since pumping induces downward vertical flow near the well. Thus, the model could not accurately simulate water levels from some shallow observation wells located in the vicinity of pumping wells. For this reason, data obtained from several shallow monitoring wells was not used for model calibration. Table K-7 compares the modeled vs. the measured water tables. The average difference between the modeled and the measured water table is 3.1 feet.

The relative average difference between the modeled and the measured water table is about 3%. The calibrated average regional infiltration rate is 12 inches per year which is within the previously estimated reasonable range of 6 to 18 inches per year. The constructed model surpassed the requirement of the predetermined calibration criteria and is suitable for further simulation and prediction.

K.5.5 SENSITIVITY ANALYSIS

The sensitivity of the TWODAN model to changes in aquifer parameters were evaluated by reviewing changes in the absolute elevation of the ground water table. The parameters critical to the regional model

Figure K-16
Simulated Water Table from the Calibrated Model
Middletown Airfield NPL Site
Middletown, Pennsylvania

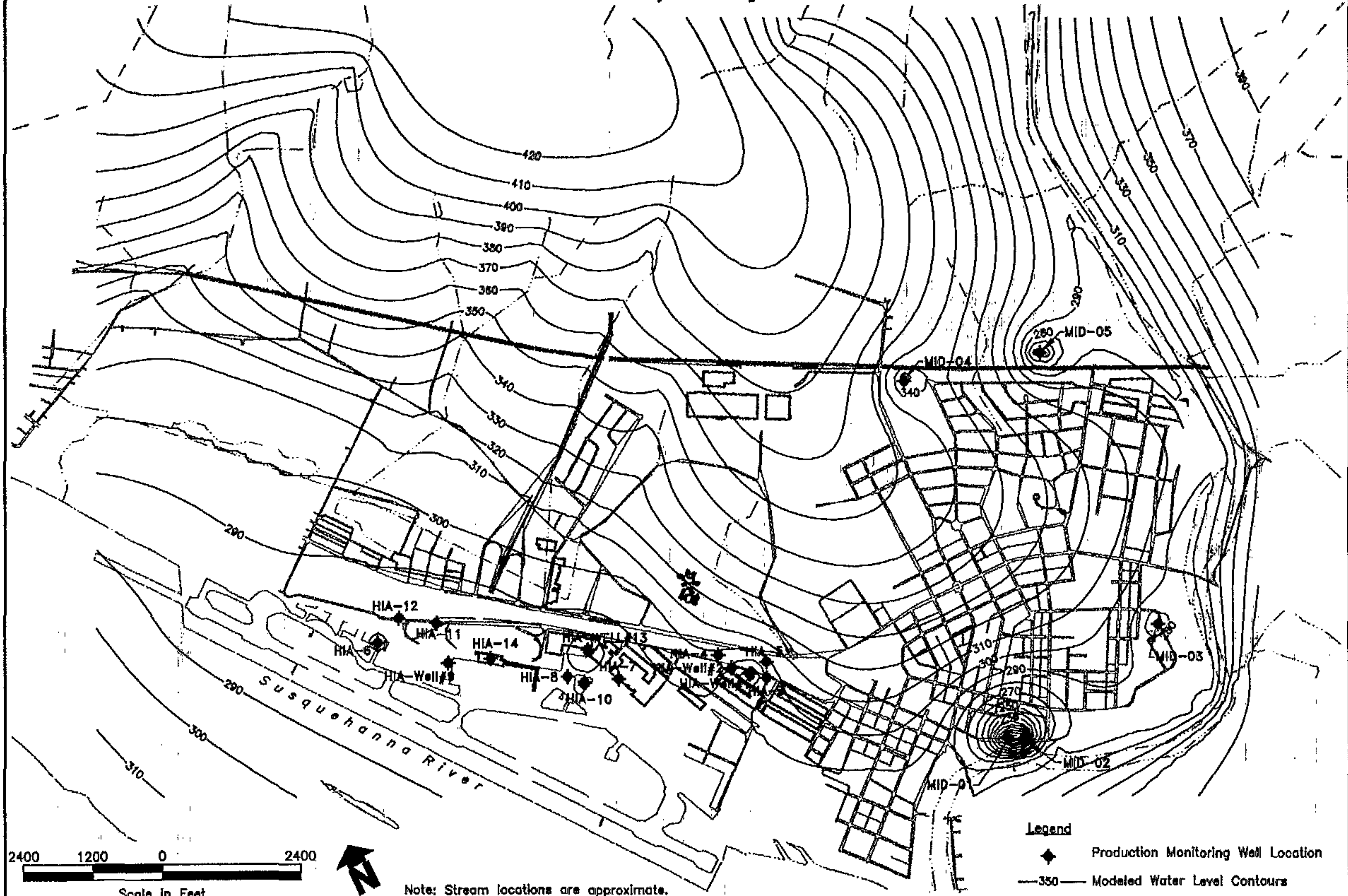


Table K-7
Calibrated Model Results
Middletown Airfield NPL Site

Well	Observed head	Modeled head	Difference	Residual
ERM-1S	288.06	289.187	1.12674	1.12674
ERM-1I	287.7	289.074	1.3739	1.3739
ERM-2S	290.74	292.684	1.94363	1.94363
ERM-3S	285.79	289.26	3.47031	3.47031
ERM-4S	285.86	285.076	-0.783691	0.783691
ERM-5S	286.06	287.943	1.8829	1.8829
ERM-6S	285.88	284.957	-0.922699	0.922699
ERM-10I	286.03	285.134	-0.895996	0.895996
ERM-27S	286.04	284.404	-1.63577	1.63577
ERM-28S	290.02	292.191	2.17145	2.17145
ERM-32I	285.47	285.93	0.459564	0.459564
ERM-32D	275.74	286.003	10.2625	10.2625
ERM-33I	286.55	291.107	4.55701	4.55701
ERM-34S	287.84	288.697	0.856567	0.856567
ERM-34I	288.06	288.751	0.691254	0.691254
ERM-35S	287.49	285.499	-1.99094	1.99094
ERM-35I	287.48	285.47	-2.01022	2.01022
GF-209	289.61	290.648	1.03839	1.03839
GF-309	289.86	290.442	0.582153	0.582153
GF-210	298.87	308.75	9.88	9.88
GF-310	298.98	308.358	9.37827	9.37827
GF-311	301.77	292.706	-9.06403	9.06403
GF-212	288.72	287.156	-1.56418	1.56418
GF-312	288.34	287.158	-1.18207	1.18207
GF-314	286.22	284.328	-1.89151	1.89151
GF-217	287.52	288.693	1.17252	1.17252
GF-317	288.4	288.861	0.460724	0.460724
GF-218	285.91	288.621	2.7114	2.7114
GF-318	286.99	288.188	1.19836	1.19836
GF-219	287.19	284.85	-2.33997	2.33997
GF-220	289.08	287.668	-1.41187	1.41187
GF-221	297.93	295.926	-2.00418	2.00418
GF-222	288.54	291.268	2.72806	2.72806
GF-223	287.54	286.826	-0.714294	0.714294
GF-227	289.65	291.34	1.68994	1.68994
ERM-21S	284.61	284.203	-0.407013	0.407013
ERM-21I	284.74	284.193	-0.547394	0.547394

Table K-7
Calibrated Model Results
Middletown Airfield NPL Site

Well	Observed head	Modeled head	Difference	Residual
ERM-21D	277.96	284.199	6.23868	6.23868
ERM-22S	284.64	284.329	-0.311066	0.311066
ERM-22I	284.32	284.345	2.49E-02	0.0249329
ERM-22D	285.12	284.342	-0.777771	0.777771
ERM-23I	274.91	276.843	1.93301	1.93301
ERM-23D	264.51	275.892	11.3821	11.3821
ERM-24I	277.46	276.145	-1.31467	1.31467
ERM-24D	262.19	276.54	14.3501	14.3501
ERM-25I	290.34	288.222	-2.11774	2.11774
ERM-25D	287.48	288.037	0.55719	0.55719
ERM-26I	289.17	282.775	-6.3949	6.3949
ERM-26D	286.65	284.491	-2.15912	2.15912
GF-203	284.85	284.059	-0.790955	0.790955
GF-204	285.24	283.468	-1.77194	1.77194
GF-205	283.88	283.559	-0.321228	0.321228
GF-305	284.09	283.395	-0.695068	0.695068
ERM-18S	285.32	284.959	-0.361298	0.361298
ERM-18I	285.07	284.931	-0.139038	0.139038
ERM-19S	286.85	286.053	-0.797211	0.797211
ERM-20S	282.76	284.044	1.28445	1.28445
ERM-20I	282.72	284.042	1.32196	1.32196
GF-207	282.07	284.106	2.03568	2.03568
GF-307	284.11	284.106	-4.24E-03	0.00424194
GF-208	283.81	284.594	0.784332	0.784332
GF-308	283.84	284.565	0.725098	0.725098
GF-215	287.65	286.09	-1.5603	1.5603
GF-315	289.82	286.109	-3.71118	3.71118
WRT-01	284.21	284.381	0.171326	0.171326
WRT-02	283.93	284.408	0.477814	0.477814
WRT-03	283.9	284.495	0.594696	0.594696
WRT-04	283.83	284.416	0.586304	0.586304
WRT-05	285.61	284.967	-0.642731	0.642731
WRT-07	282.95	284.531	1.58118	1.58118
ERM-11S	358.85	370.101	11.2512	11.2512
ERM-11I	359.52	370.612	11.0919	11.0919
ERM-12S	374.78	371.167	-3.61343	3.61343
ERM-12I	363.37	370.904	7.53375	7.53375

Table K-7
Calibrated Model Results
Middletown Airfield NPL Site

Well	Observed head	Modeled head	Difference	Residual
ERM-13S	370.23	378.216	7.9856	7.9856
ERM-13I	369.51	378.109	8.59872	8.59872
ERM-14S	370.69	380.323	9.63281	9.63281
ERM-14I	370.12	380.454	10.334	10.334
ERM-15I	385.7	380.755	-4.9447	4.9447
ERM-16S	365.47	370.558	5.08813	5.08813
ERM-16I	361.74	370.383	8.64316	8.64316
ERM-17S	352.66	357.859	5.19894	5.19894
ERM-17I	355.71	358.182	2.47205	2.47205
ERM-29S	344.6	350.693	6.09293	6.09293
ERM-29I	354.6	350.636	-3.96414	3.96414
ERM-30S	358.01	363.324	5.31442	5.31442
ERM-30I	358.67	363.479	4.80878	4.80878
GF-301	385.29	374.996	-10.2944	10.2944
GF-303	369.72	369.466	-0.254059	0.254059
GF-250	341.1	340.239	-0.86142	0.86142
	Minimum Head	275.892		
	Maximum Head	380.755		
	Average Residual	3.17		
	Minimum Residual	0.00		
	Maximum Residual	14.35		
	Model Fit	3.02%		

calibration are the areal infiltration rate and transmissivity. The TWODAN model responded in a predictable fashion to varying transmissivity and infiltration input values. An increase in transmissivity caused a lowering of the water table, as did a decrease in the areal infiltration rate. A decrease in transmissivity caused the water table to rise, as did an increase in the areal infiltration rate. The water table elevation was also affected by the difference in transmissivity between adjacent heterogeneity elements.

Figures K-17 through K-19 illustrate the capture zones for Scenario 1 pumping with a varying infiltration rate from 6 inches per year to 12 inches per year to 18 inches per year. Variation of the infiltration rate had a minimal effect on the ground water flow direction, which is consistently from the north to northeast. However, the lower infiltration rate resulted in wider simulated capture zones. An areal recharge rate of 12 inches per year was used as representative of field conditions in the model calibration and simulation of model scenarios.

The aquifer porosity does not affect the water table elevation, however, it will affect the ground water travel time. As the porosity increases or decreases, modeled ground water travels proportionally slower or faster, respectively. In summary, no unusual or extreme model sensitivities were noted.

K.5.6 MODEL SIMULATION AND DISCUSSION

Once the model was calibrated, it was used to simulate well capture zones for four different pumping scenarios, as listed in Table K-8. Scenarios 1, 2, and 3 were selected based on typical HIA well configurations recorded during the ambient monitoring period and just prior to the start of the capture zone tests. The average daily pumping rates of the HIA production wells and the average annual pumping rates for the Middletown Borough wells were used in these scenarios. Both Scenarios 1 and 2 have HIA-13 as lead well, which is the most common configuration. A less typical configuration is Scenario 3 with HIA-13 off-line. Figures K-17, K-20 and K-21 illustrate the capture zones for Scenarios 1, 2, and 3, respectively. It is important to keep in mind while viewing these figures that the extent of the capture zones are calculated for a 16 year time period and do not reflect the variability of the "on-demand" operation of the HIA system.

Figure K-17
Scenario 1 (6"/yr recharge) - Capture Zones of Production Wells
Middletown Airfield NPL Site
Middletown, Pennsylvania

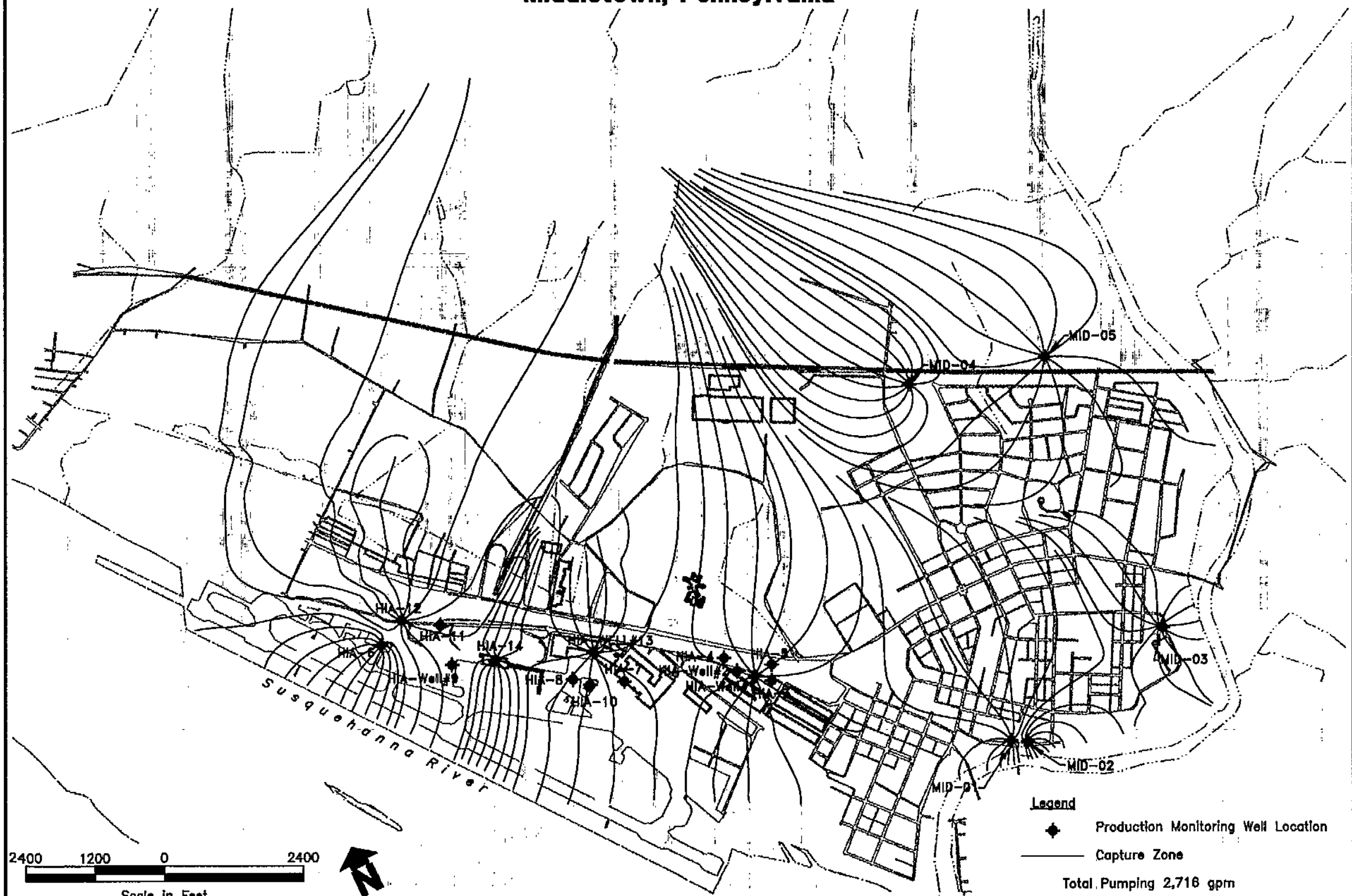


Figure K-18
Scenario 1 (12"/yr recharge) - Capture Zones of Production Wells
Middletown Airfield NPL Site
Middletown, Pennsylvania

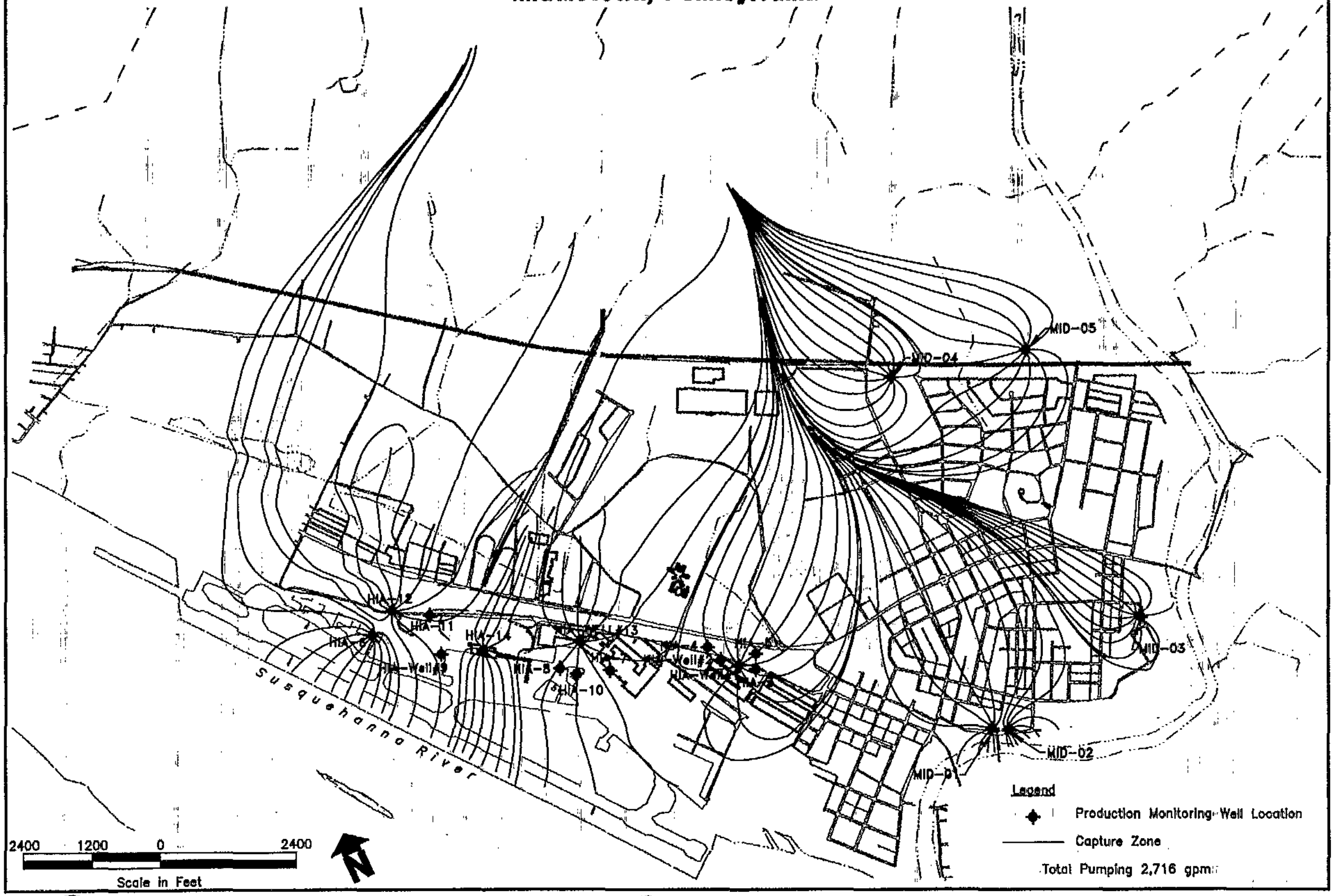


Figure K-19
Scenario 1 (18"/yr recharge) - Capture Zones of Production Wells
Middletown Airfield NPL Site
Middletown, Pennsylvania

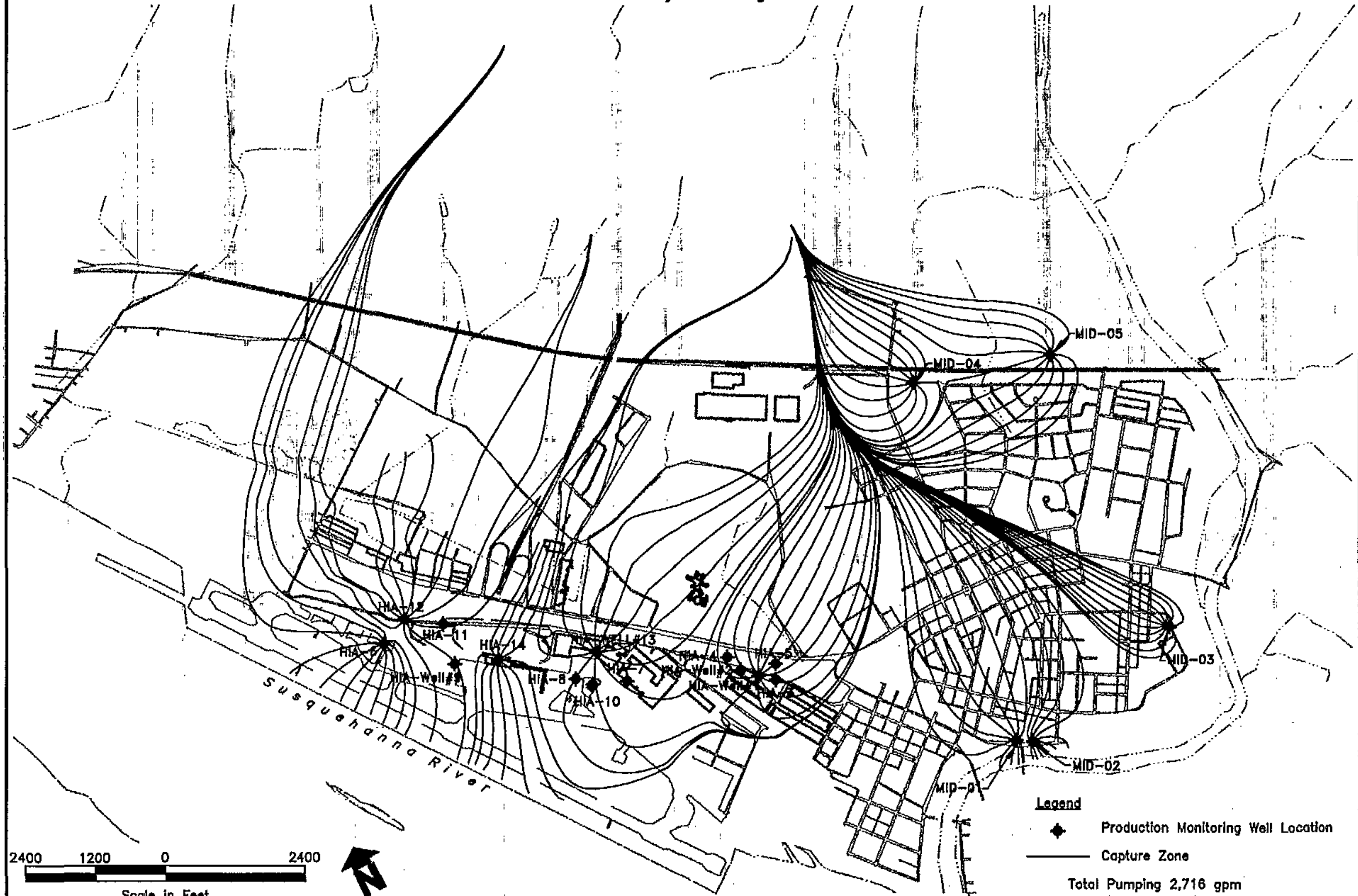
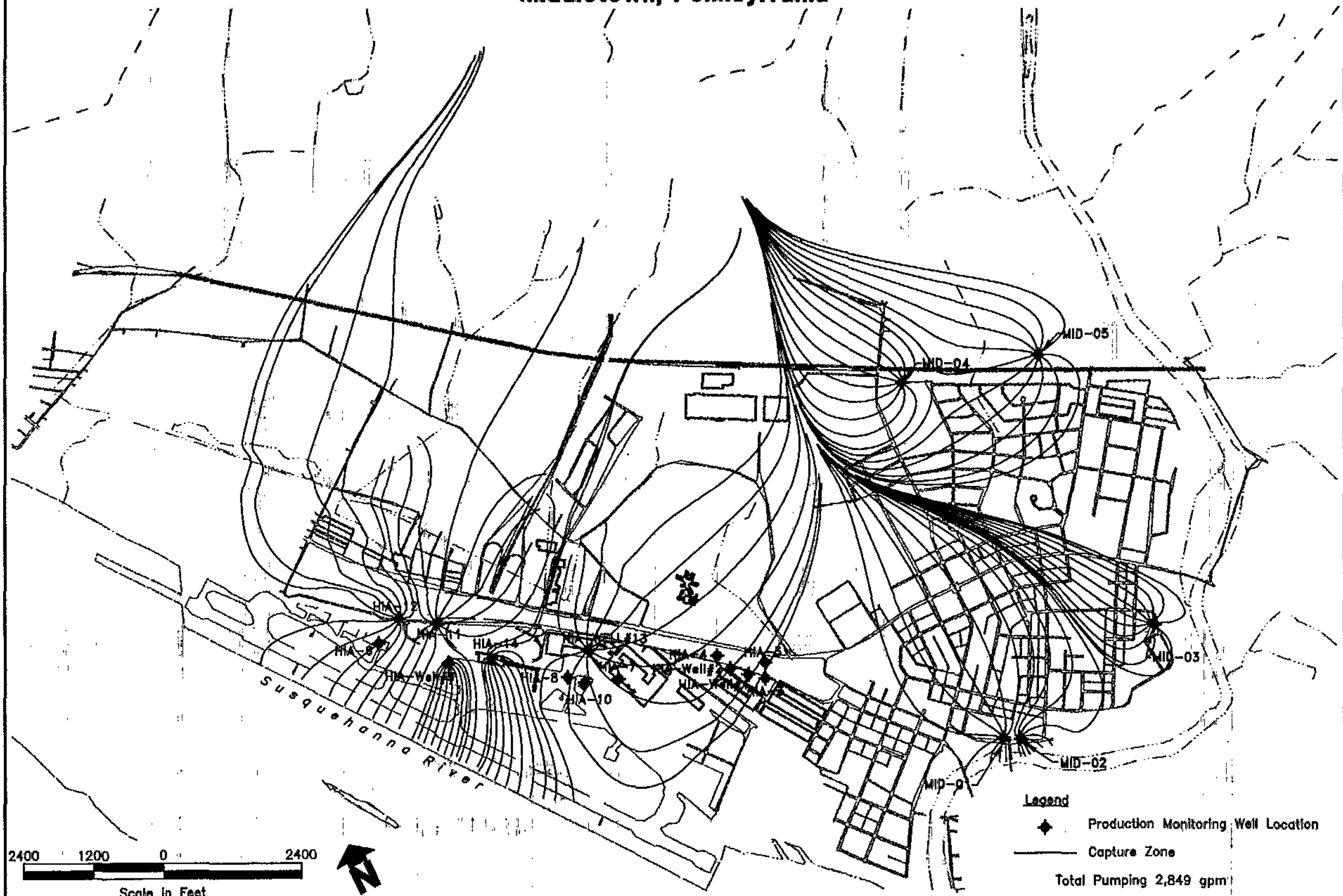


Figure K-20
Scenario 2 - Capture Zones of Production Wells
Middletown Airfield NPL Site
Middletown, Pennsylvania



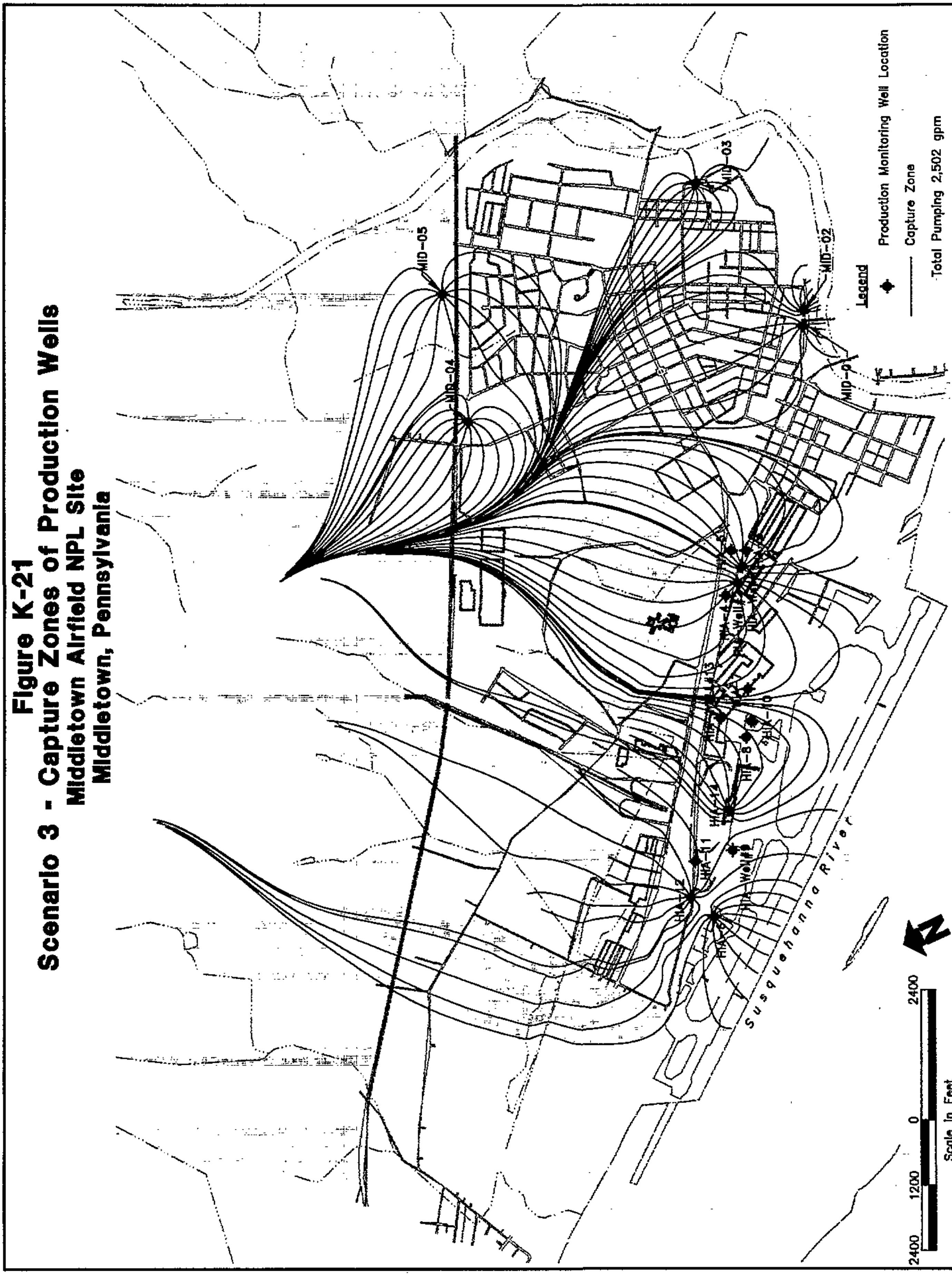


Figure K-21
Scenario 3 - Capture Zones of Production Wells
Middletown Airfield NPL Site
Middletown, Pennsylvania
MID-05
MID-04
MID-03
MID-02
MID-01
Susquehanna River
Legend
Production Monitoring Well Location
Capture Zone
Total Pumping 2,502 gpm
2400 1200 0 2400
Scale in Feet

Table K-8
Model Scenarios for Capture Zone Analysis
Middletown Airfield NPL Site

Well	Model Scenarios						
	1 (1-Aug-95)		2 (28-Jul-95)		3 (26-Sep-95)		4
	Pump Rate (gpm)	Well Designation	Pump Rate (gpm)	Well Designation	Pump Rate (gpm)	Well Designation	Annual Average Pump Rate (gpm)
HIA-1	200	2nd Lag			160	2nd Lead	35
HIA-2					230	2nd Lag	46.2
HIA-3							
HIA-4							
HIA-5							14.4
HIA-6	460	1st Lag			490	1st Lag	75
HIA-9			196	2nd Lag			
HIA-11			604	1st Lag			90
HIA-12	667	2nd Lead	650	2nd Lead	630	1st Lead	96
HIA-13	397	1st Lead	407	1st Lead			195
HIA-14(HVAC)	160		160		160		160
MID-01	295		295		295		295
MID-02	214		214		214		214
MID-03	67		67		67		67
MID-04	89		89		89		89
MID-05	167		167		167		167

Scenario 4 simulates the annual average pumping rates for all the active HIA production wells and all five of the Middletown Borough wells. HIA wells (HIA-2, 3, and 9) with annual average pumping rates of less than 15 gpm were not included in Scenario 4.

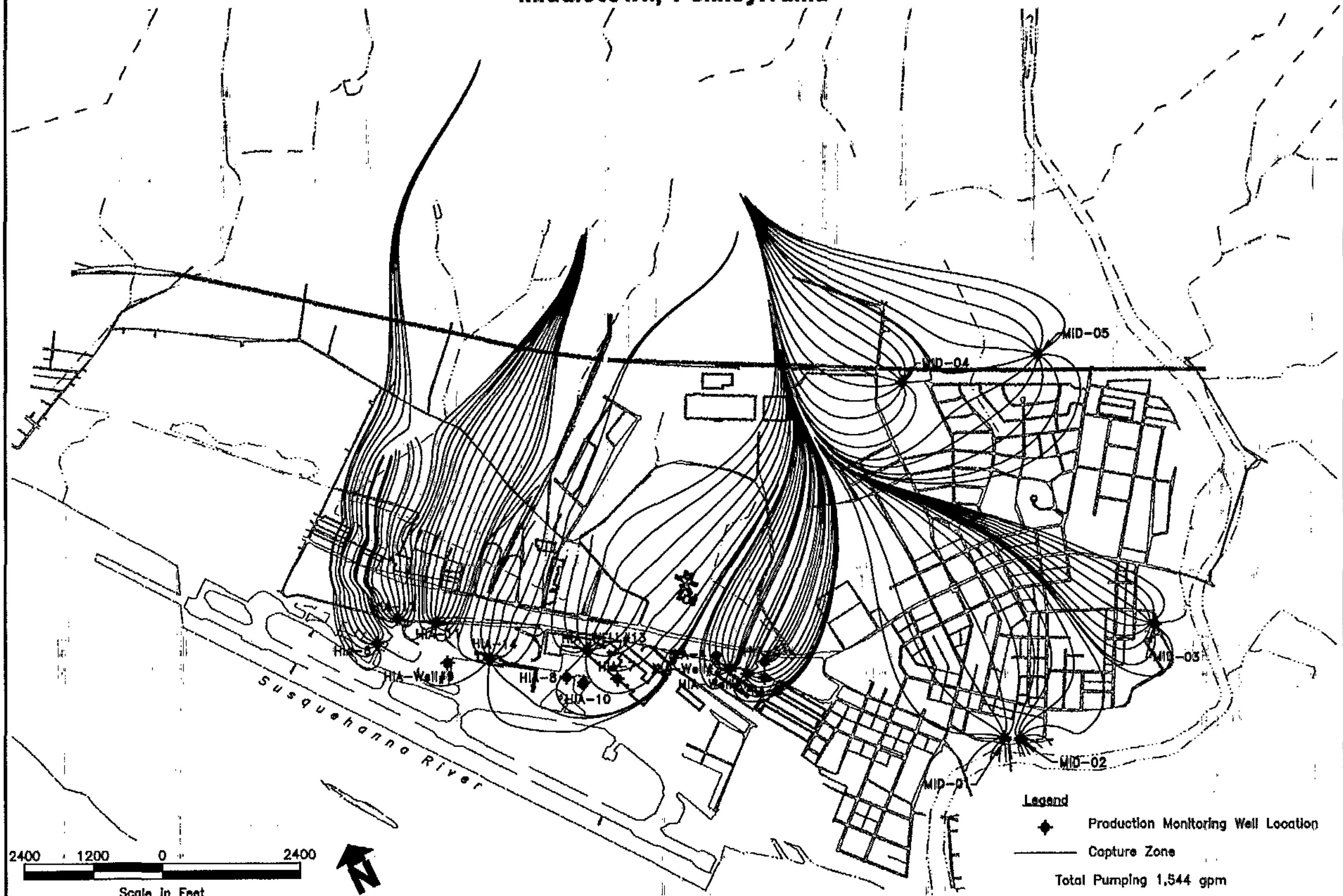
Figure K-22 illustrates the capture zones of production wells pumping at their average annual rates (Scenario 4). These capture zones were calculated for a 16 year time period, which was arbitrarily chosen. Because of the extended time period, Scenario 4 which simulates average annual pumping rates is more representative of actual site conditions. A greater apparent capture may be observed from water level data if a pump is operating at a rate greater than its average annual rate as seen in scenarios 1, 2 and 3. The actual contaminant migration rates are probably slower than the ground water travel time due to retardation. In general, HIA production wells capture the majority of the ground water that comes from north of the Industrial Area. The area of influence does not extend south of the Runway in the Western Area and Central Area and south of Building 100 (Federal Express) and the road off of Airport Drive which forms the northern boundary of the PAANG compound in the Eastern Area.

Based on the isotropic ground water flow model, the majority of the HIA production wells receive water from the north to northeast, thus any source located north of the HIA production wells may have a potential impact on them. The Middletown Borough wells receive water from the north and west, thus any source located between north and west of the MID wells has the potential to impact them.

K.5.6.1 Eastern Area

The Eastern Area contains production wells HIA-1, -2, -3, -4 and -5. Under average annual pumping conditions (Scenario 4), the wells created capture zones approximately 2,000 feet wide and extending 2,000 feet north to northeast as illustrated in Figure K-22. The capture zone does not extend south of Building 100 (Federal Express) and the road off of Airport Drive which forms the northern boundary of the PAANG compound in the Eastern Area. Under the higher average daily pumping conditions of Scenario 3, the capture zone created by the Eastern Area production wells was 4,000 feet wide and extended 3,000 north to northeast and just south of the PAANG compound as illustrated in Figure K-21.

Figure K-22
Scenario 4 - Capture Zones of Production Wells - Average Annual Pumping Conditions
Middletown Airfield NPL Site
Middletown, Pennsylvania



K.5.6.2 *Central Area*

The Central Area contains production wells HIA-7, -8, -10, and -13. Under average annual pumping conditions (Scenario 4), the wells created capture zones approximately 2,000 feet wide and extending 6,000 feet to the northeast and 1,200 feet to the south of HIA-13 as illustrated in Figure K-22. Two surface water tributaries intercept a portion of ground water within these well capture zones, as can be readily seen from the flattened boundaries of the well capture zones.

K.5.6.3 *Western Area*

The Western Area contains production wells HIA-6, -9, -11, -12 and -14. Under average annual pumping conditions (Scenario 4), the wells created capture zones approximately 3,000 feet wide and extending 7,000 feet to the north as illustrated in Figure K-22. The capture zone does not extend south of the runway. A surface water tributary captured a portion of ground water within these capture zones. A portion of water came from two surface water ponds north to northwest of this area.

K.5.6.4 *North Base Landfill*

The North Base Landfill contains production well MID-04. Under average annual pumping conditions (Scenario 4), this well creates a capture zone approximately 3,000 feet wide and extending 2,000 feet northwest as illustrated in Figure K-22.

K.6 CONCLUSIONS AND RECOMMENDATIONS

K.6.1 Capture Zone Test

The results of the pumping tests provided good estimates of the aquifer transmissivity in the Industrial Area and the North Base Landfill Area. On a regional scale, anisotropic conditions may effect ground water flow, however, the pumping tests performed could not identify these effects. The HIA-2 test results suggested that some anisotropy may exist in the Eastern Area with an anisotropy ratio of approximately 1.2 : 1. Although the test data from the Central Area (HIA-13) indicated that the transmissivity in the direction normal to strike was greater than along strike (i.e., ERM-24D drewdown more than ERM-23D), exactly opposite what was expected.

Due to heterogeneous conditions, aquifer storage coefficients and horizontal to vertical anisotropy could not be determined. The lack of a horizontal to vertical anisotropy measurement will complicate future 3-dimensional modeling as this ratio is important to evaluating the 3-dimensional influence of the pumping wells.

The pumping test results demonstrate that the transmissivity of the bedrock aquifer is increasing moving from the North Base Landfill Area toward the Industrial Area and from east to west. The Western Area exhibited an aquifer transmissivity approximately 25 times greater than the North Base Landfill Area. This is likely due to increased fracturing in the bedrock in the Western Area.

K.6.2 Capture Zone Analysis

The regional ground water model constructed for the Middletown Airfield achieved good calibration to the field measured data, pumping test results, and the estimated areal infiltration rate.

The model simulated capture zone of the production wells under average annual pumping conditions are illustrated in Figure K-22. These capture zones cover a significant portion of the Site area. The time frame of the capture zone simulation is 16 years. Ground water contamination located to the north within these capture zones would have a potential to migrate into these production wells within the simulated time frame.

The model has concluded that the contaminants detected south of the HIA-2 area can not be contained by the production wells in this area. Unless additional remedial measures are taken, contaminants will continue migrating toward Susquehanna River.

The model also concluded that migration of contaminants leached from the North Base Landfill, located to the west of MID-04, would be influenced by the pumping of MID-04 .

K.7 REFERENCES

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Attachment K1
Arithmetic Data Plots
Ground Water Elevation vs. Time

Hydrographs-Pumping Test HIA-2

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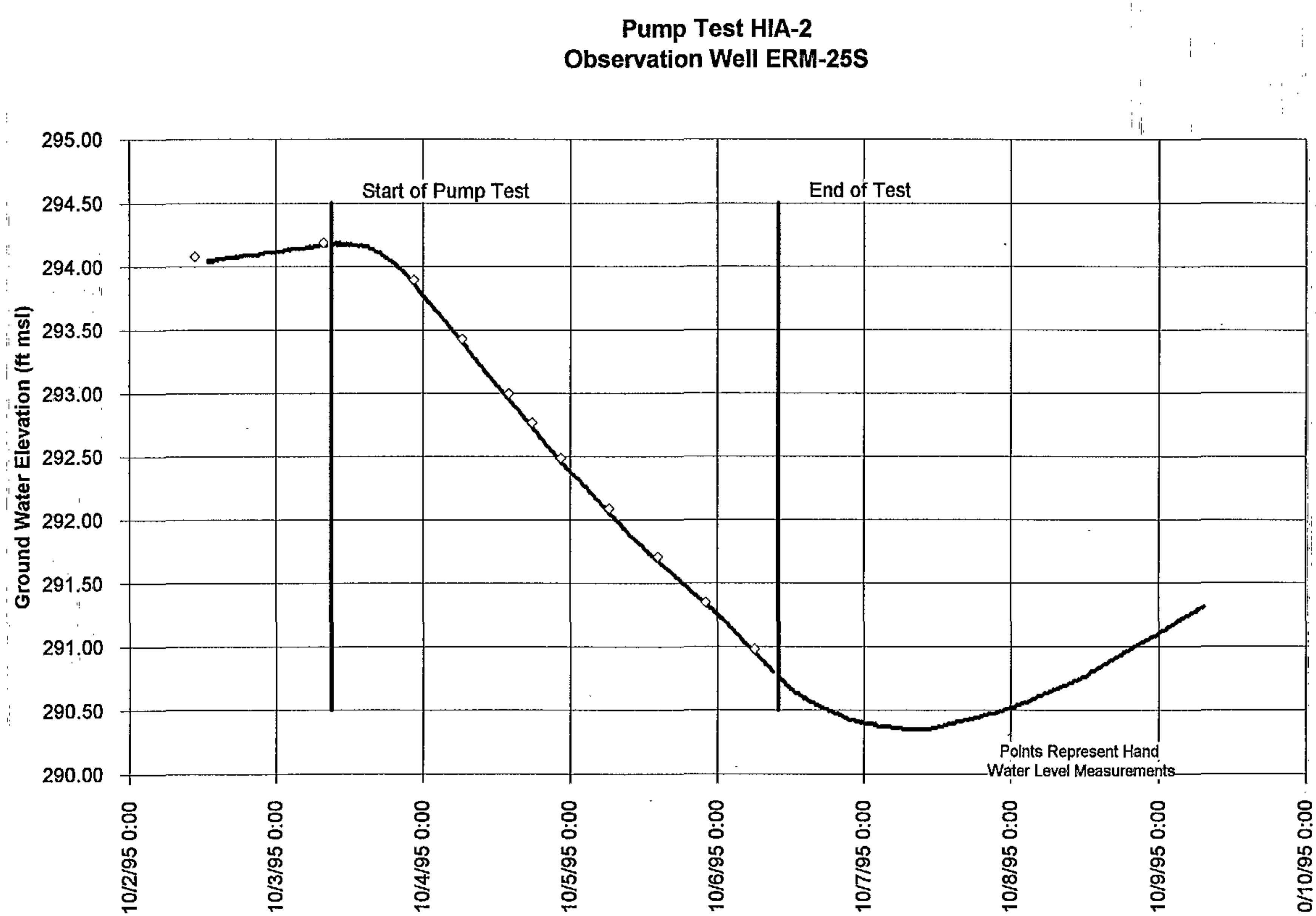
Date Printed: 11/3/95



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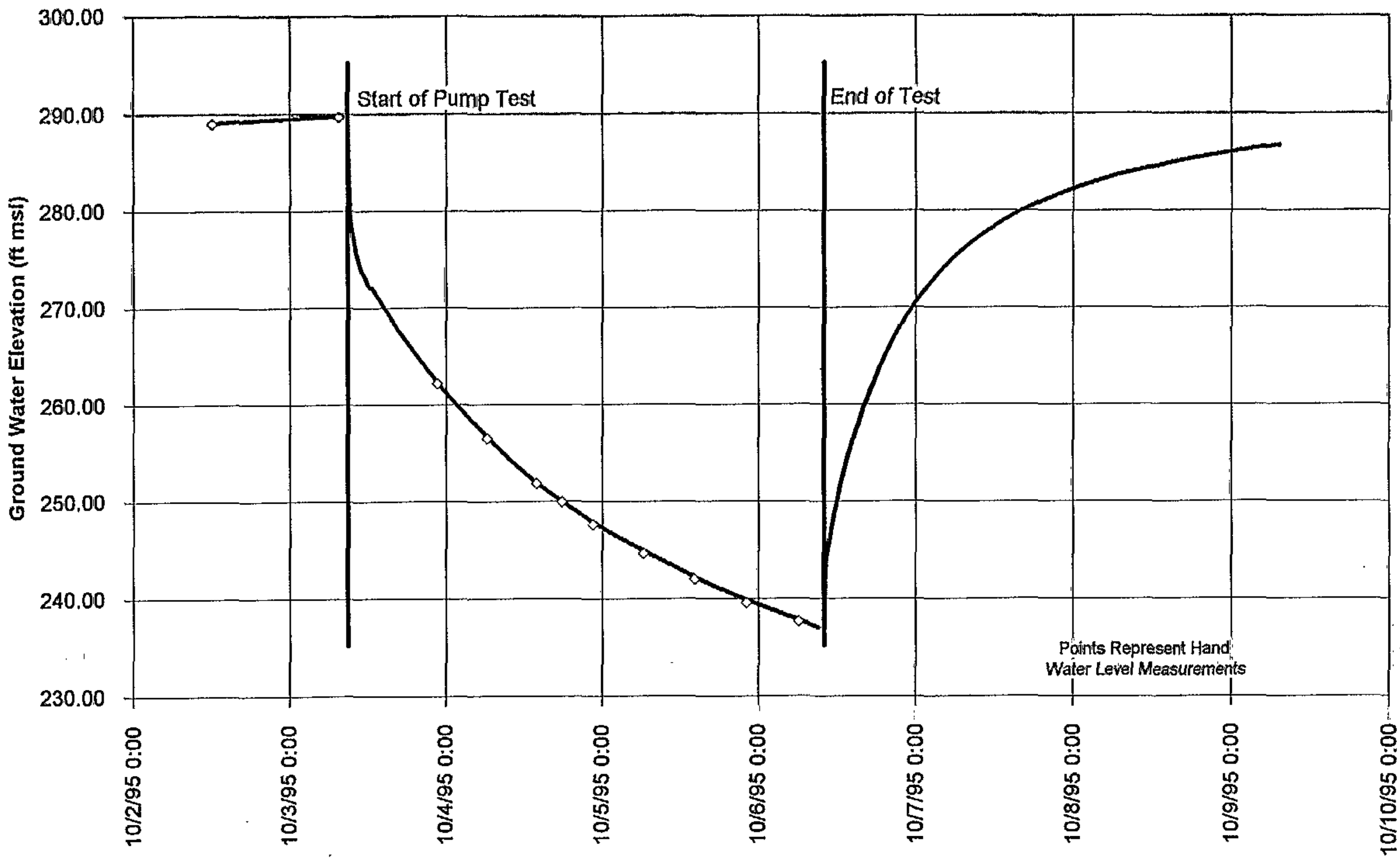
Pump Test HIA-2
Observation Well ERM-25I



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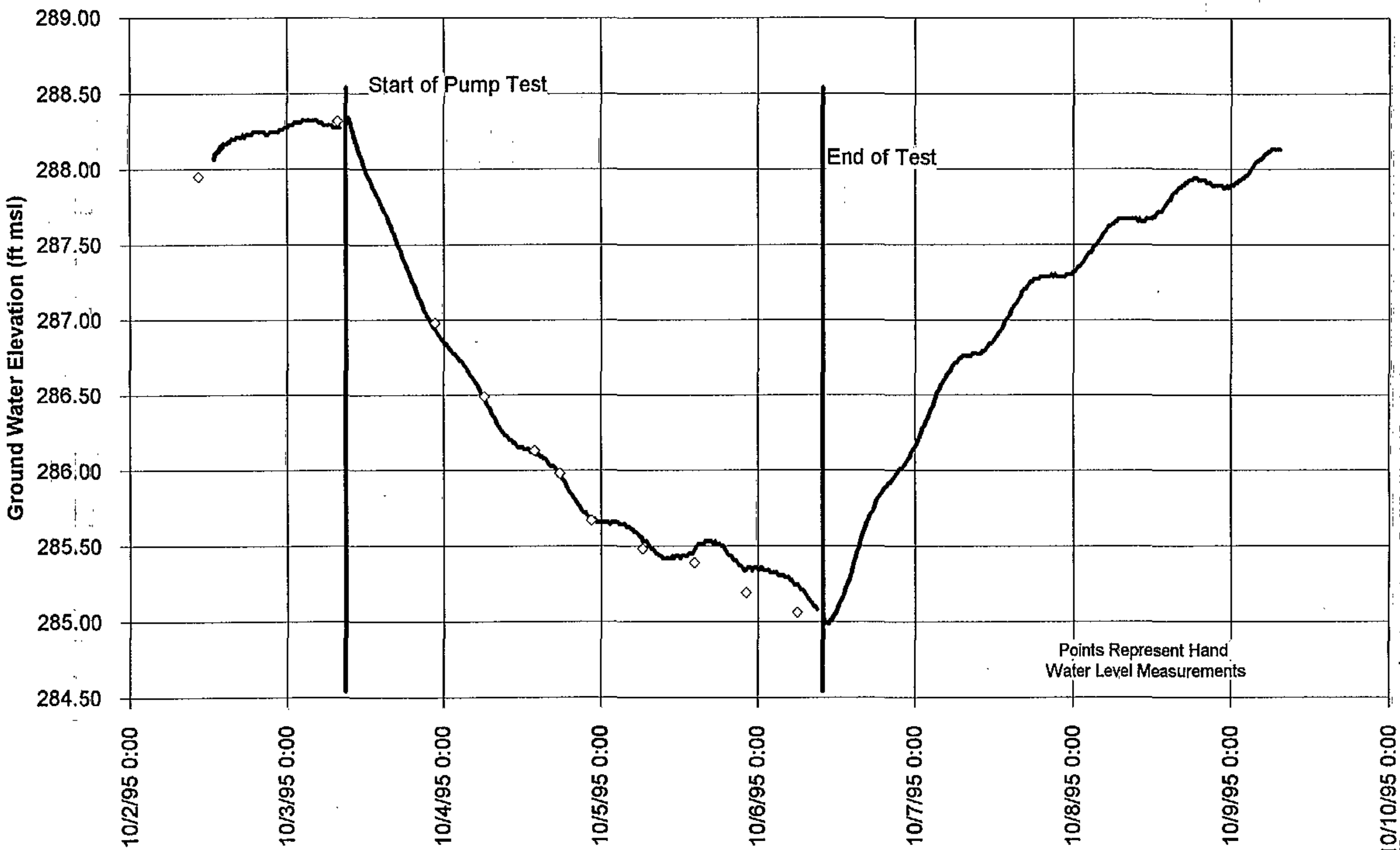
Observation Well ERM-25D



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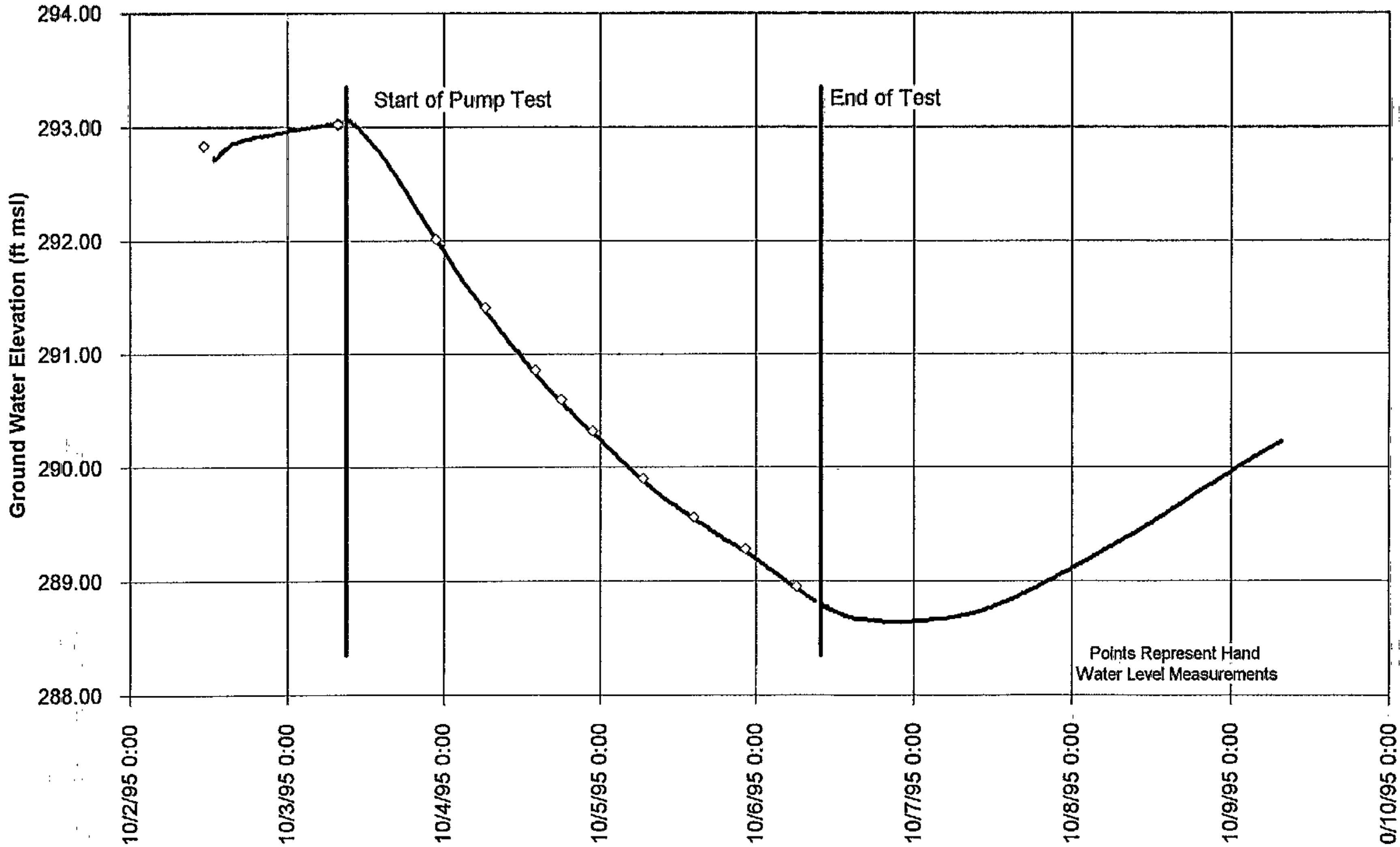
Observation Well ERM-26S



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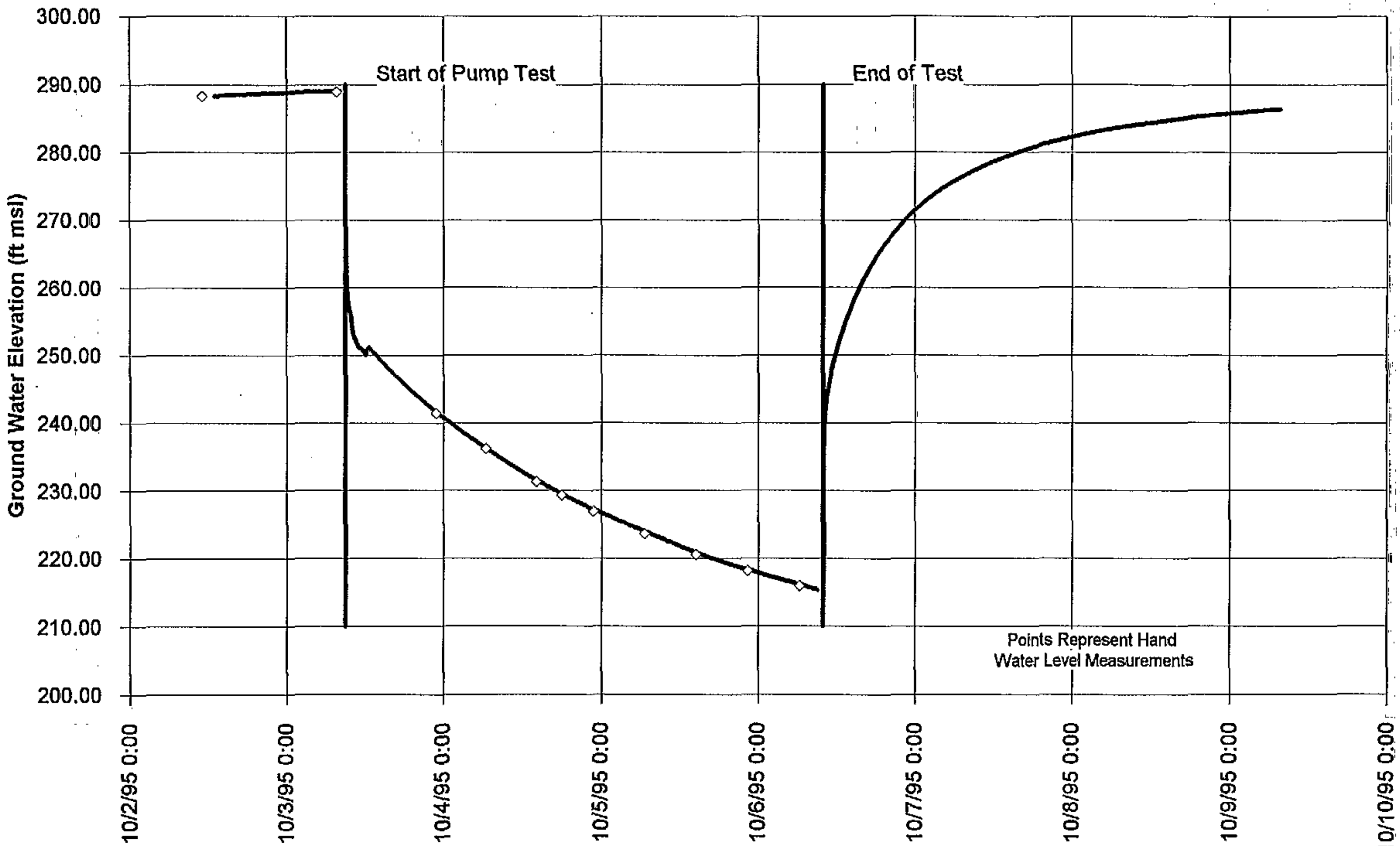

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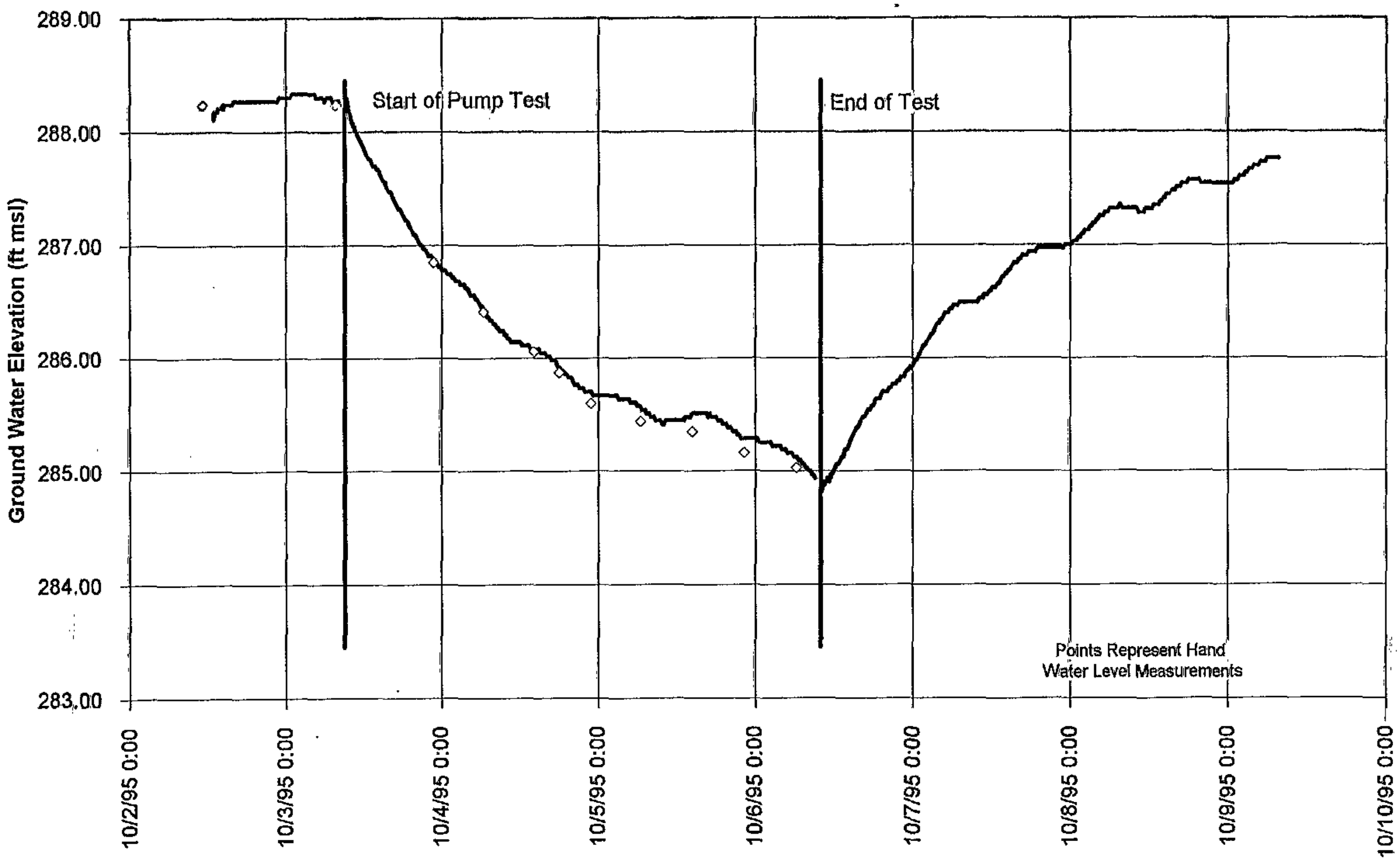

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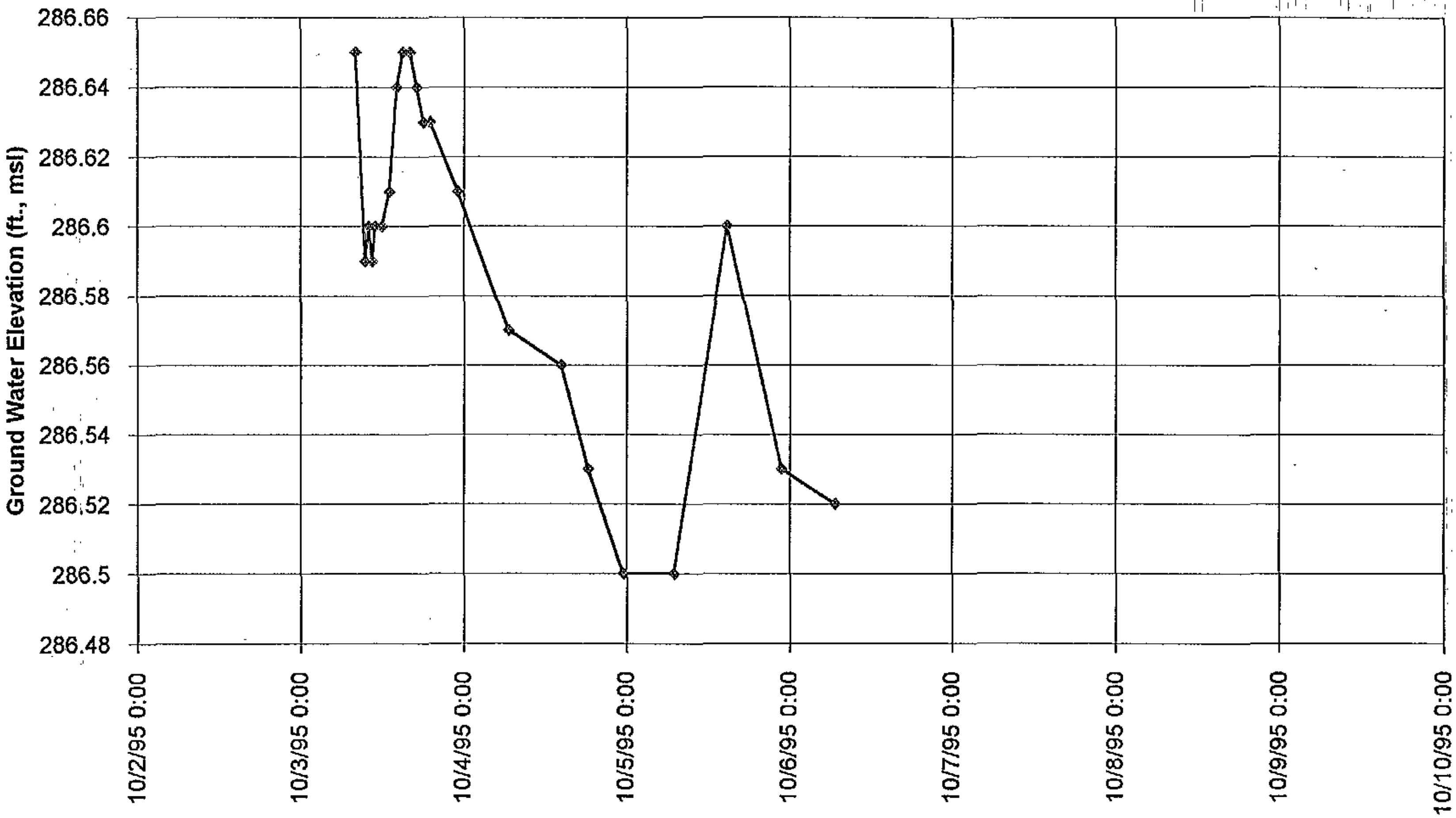
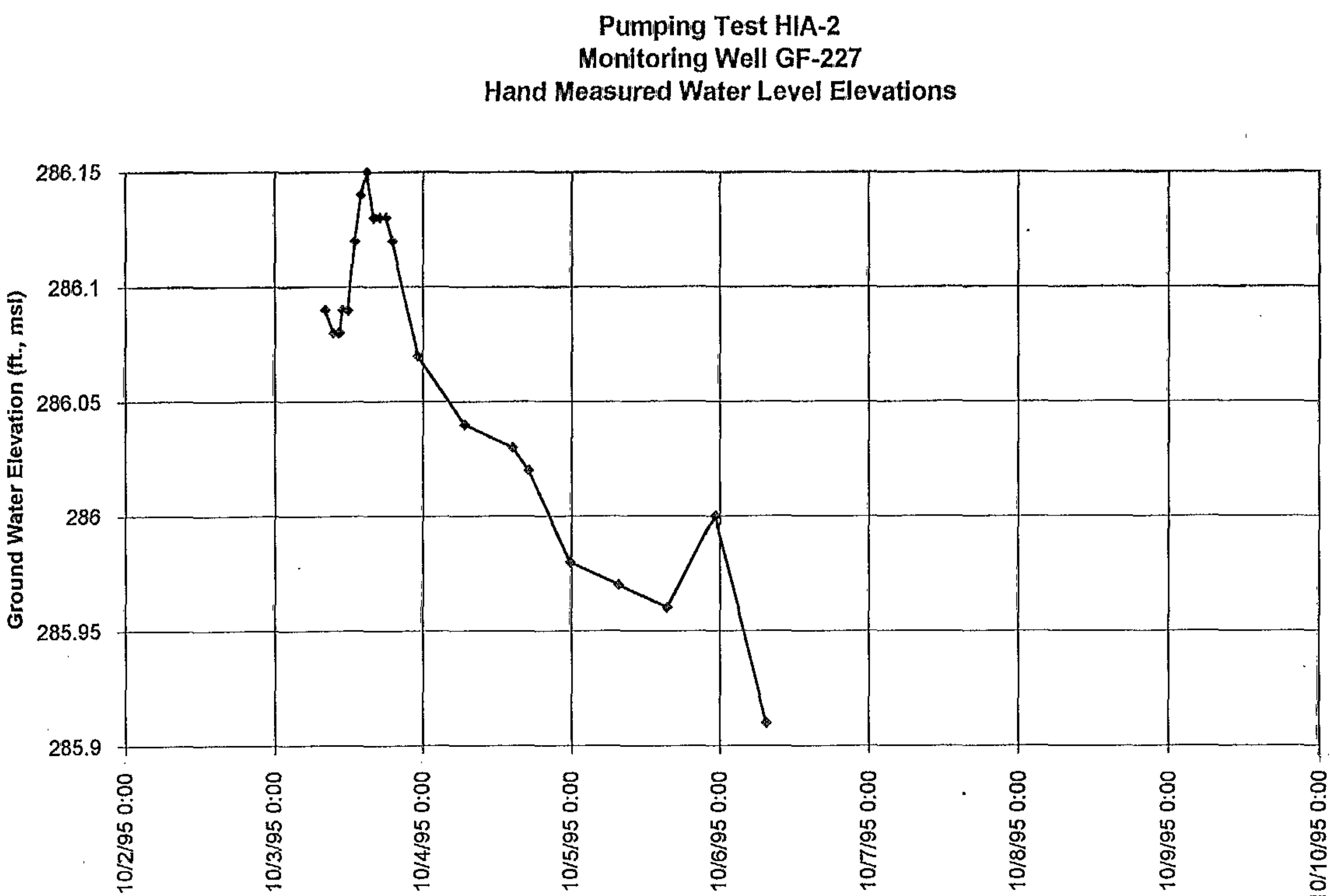
Pumping Test HIA-2
Monitoring Well ERM-28S
Hand Measured Water Level Elevations



THE ERM GROUP


Pumping Test HIA-2
Monitoring Well GF-227
Hand Measured Water Level Elevations
Ground Water Elevation (ft., msl)
286.15
286.1
286.05
286
285.95
285.9
10/2/95 0:00
10/3/95 0:00
10/4/95 0:00
10/5/95 0:00
10/6/95 0:00
10/7/95 0:00
10/8/95 0:00
10/9/95 0:00
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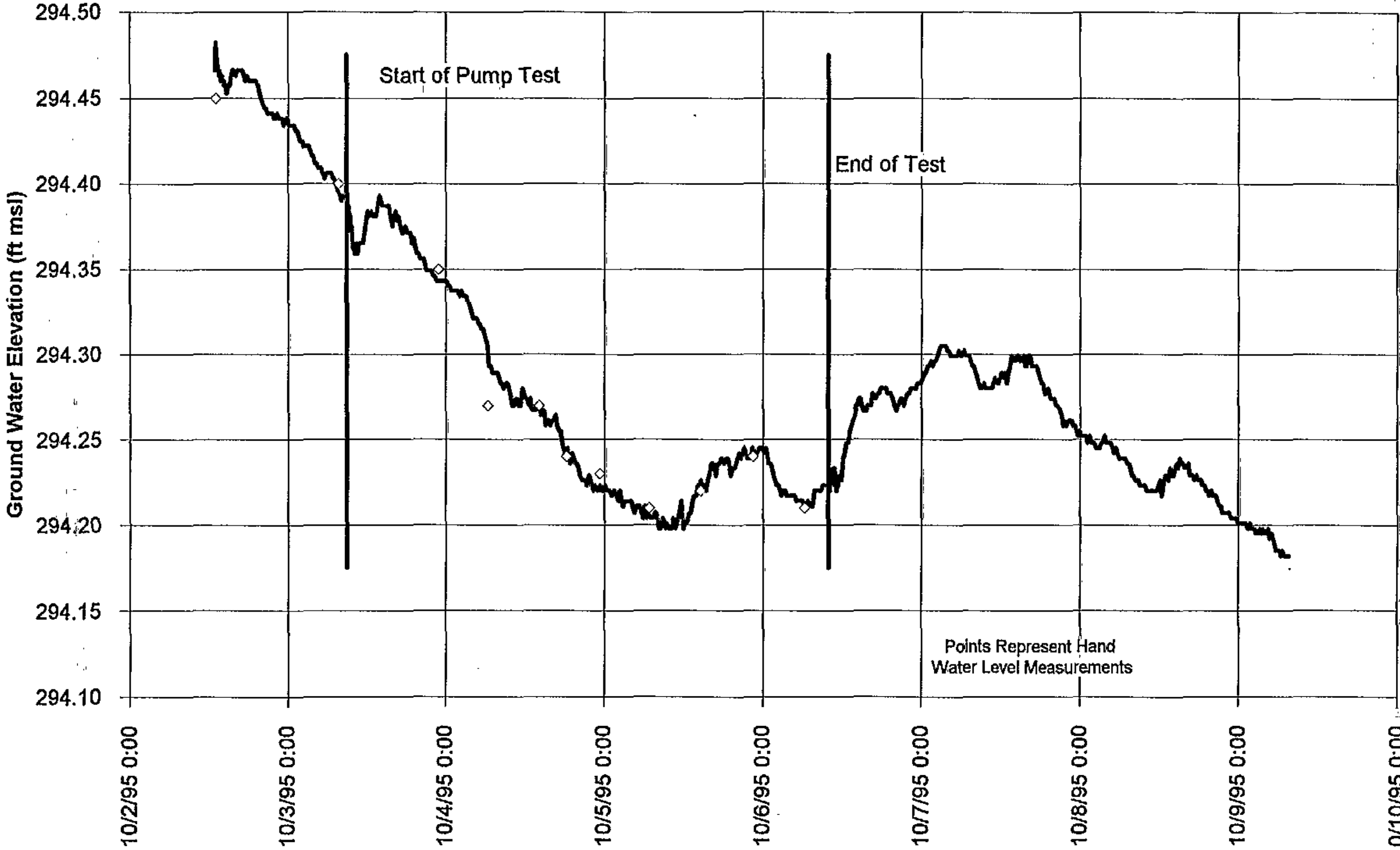
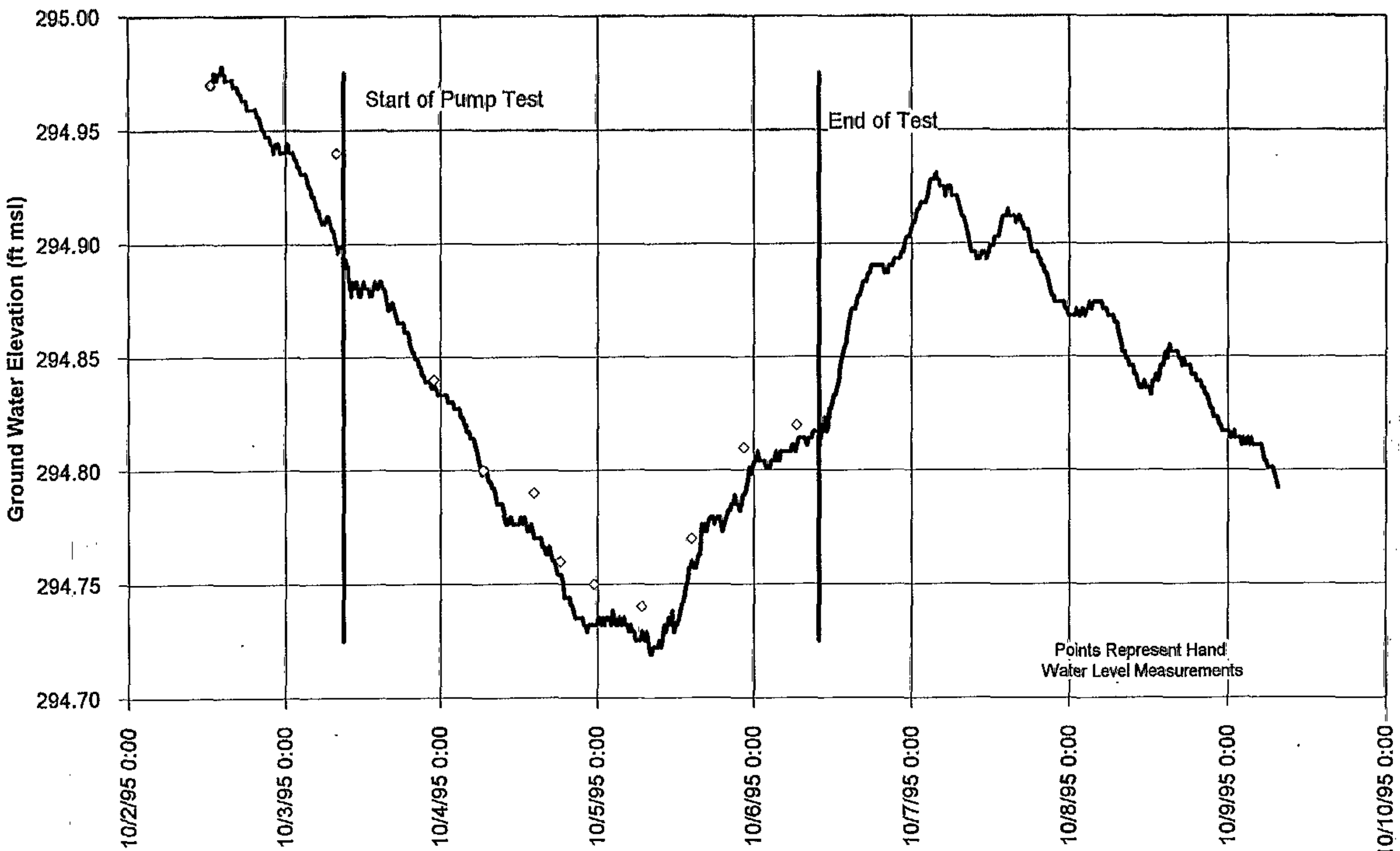
Date Printed: 11/3/95

Pump Test HIA-2
Observation Well GF-210



THE ERM GROUP

Pumping Test HIA-2
Observation Well GF-310



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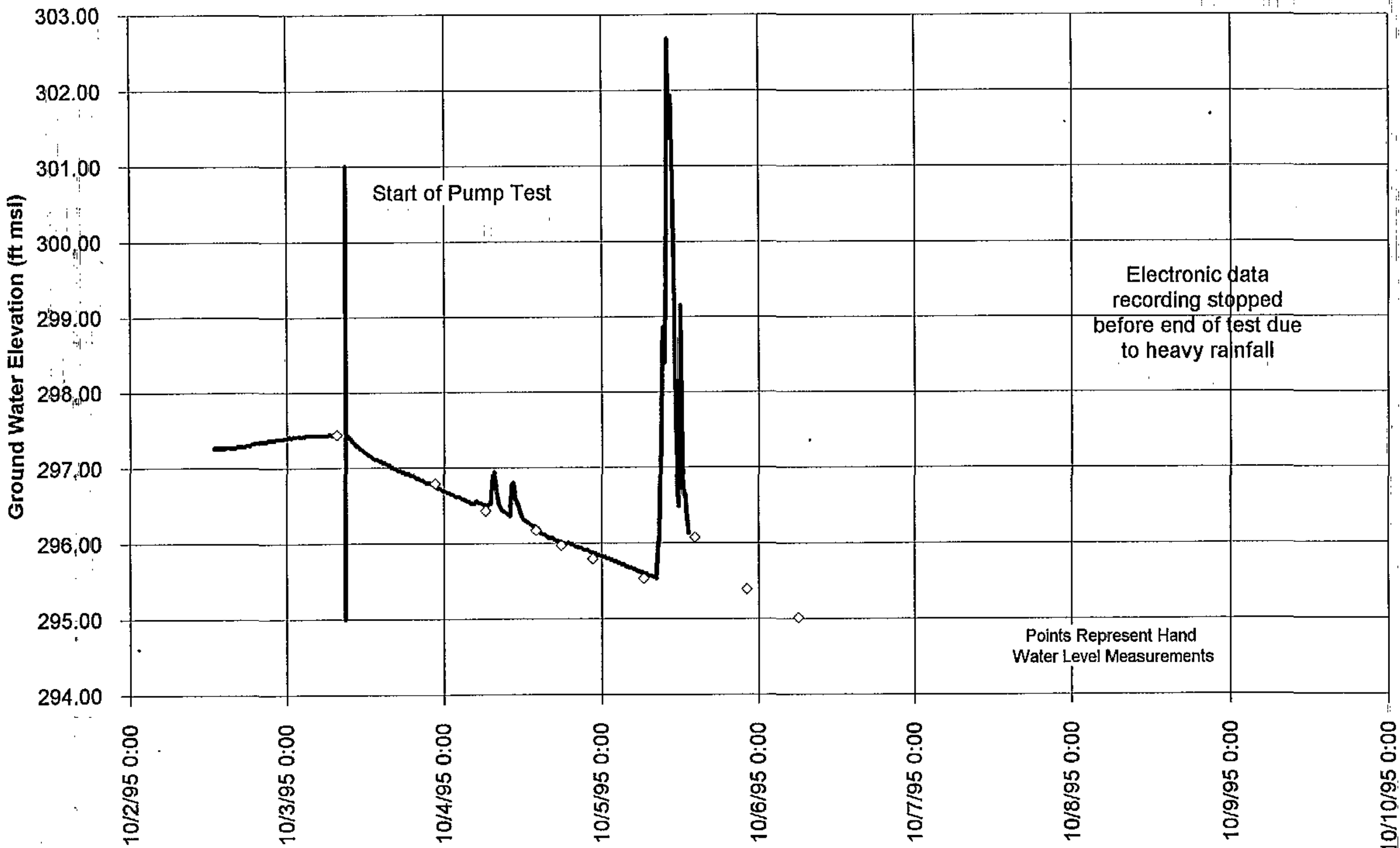
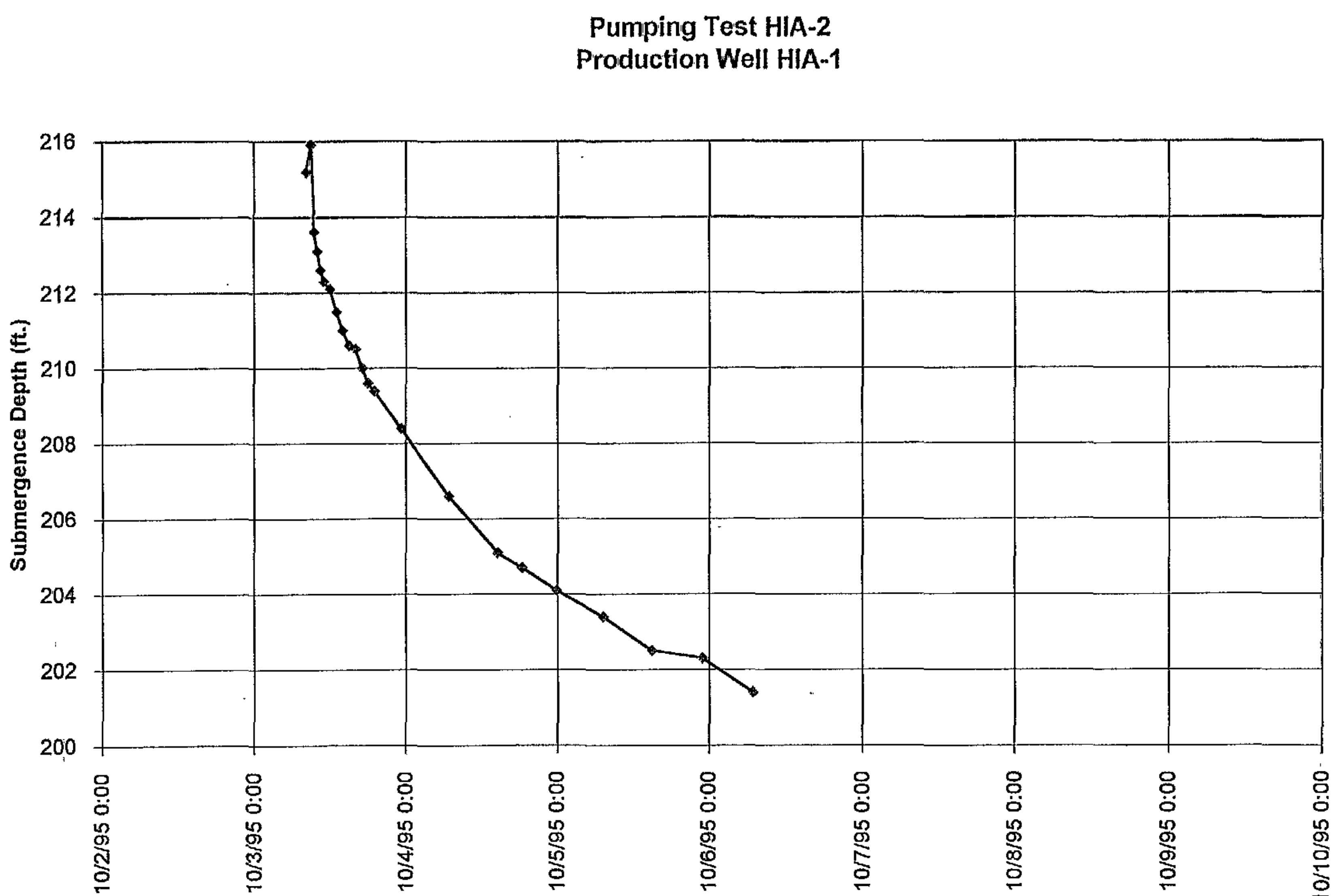
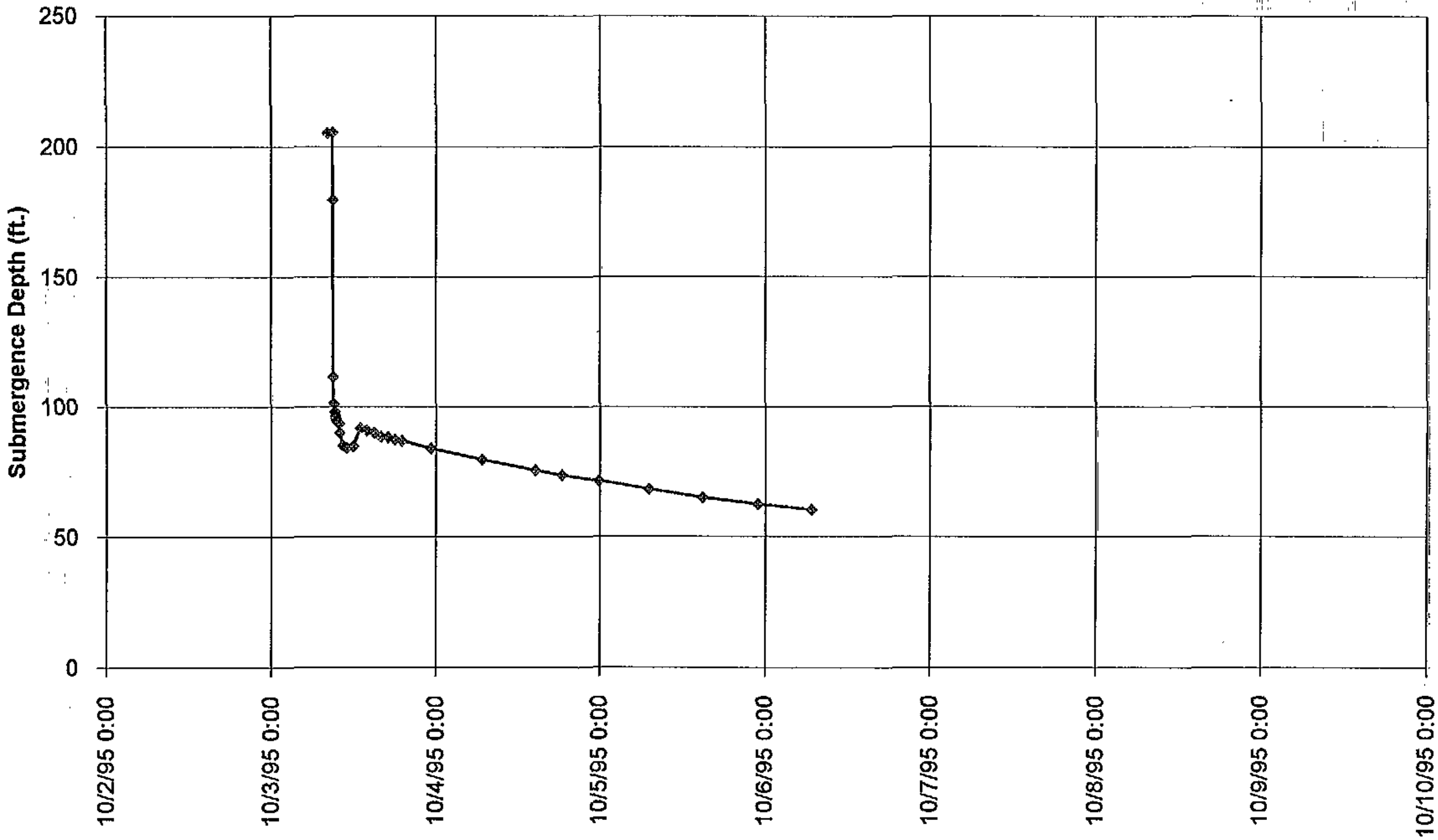
Observation Well GF-311




Pumping Test HIA-2
Production Well HIA-1
Submergence Depth (ft.)
216
214
212
210
208
206
204
202
200
10/2/95 0:00
10/3/95 0:00
10/4/95 0:00
10/5/95 0:00
10/6/95 0:00
10/7/95 0:00
10/8/95 0:00
10/9/95 0:00
10/10/95 0:00

Pumping Test HIA-2
Production Well HIA-2



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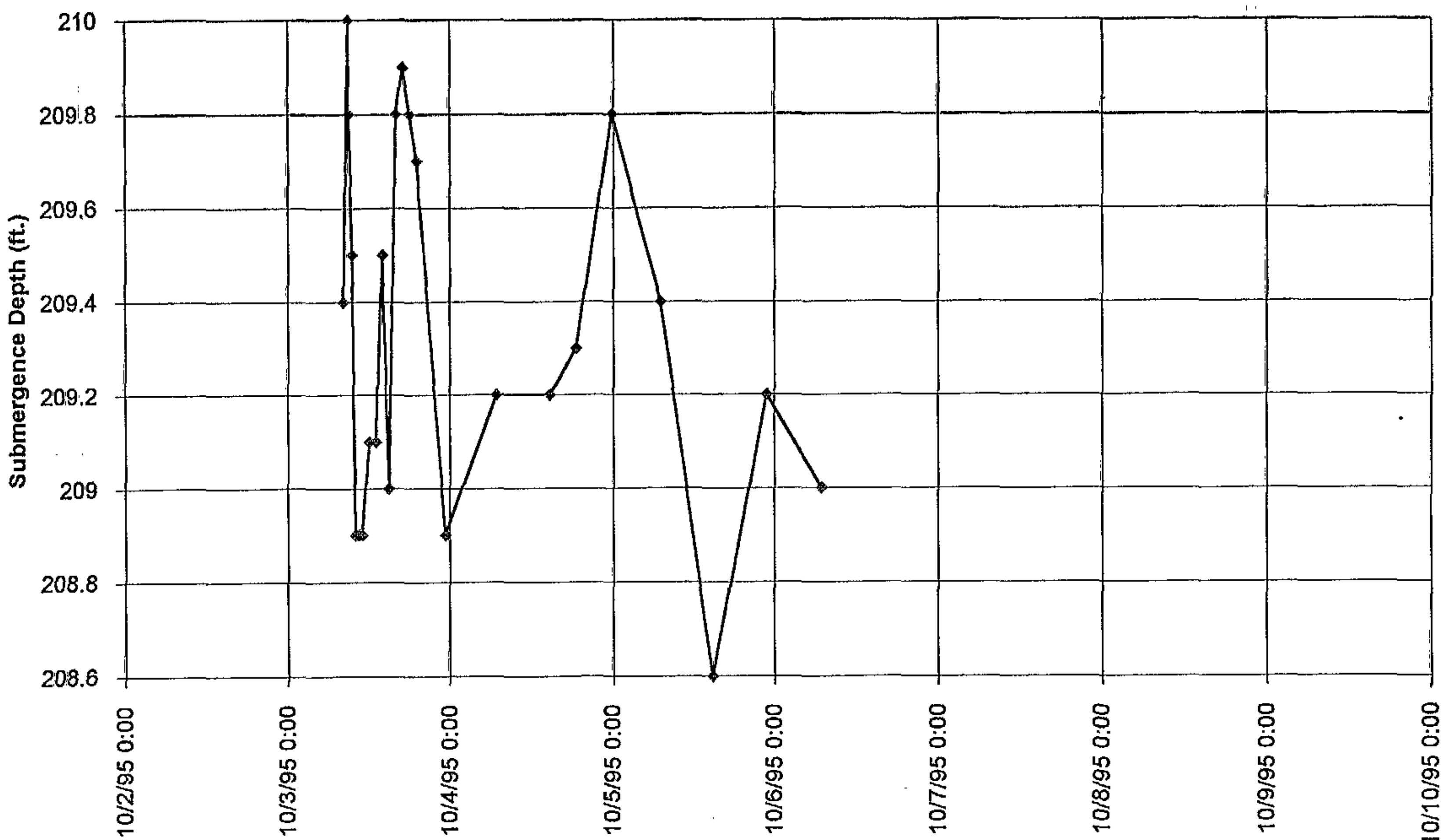
Production Well HIA-3



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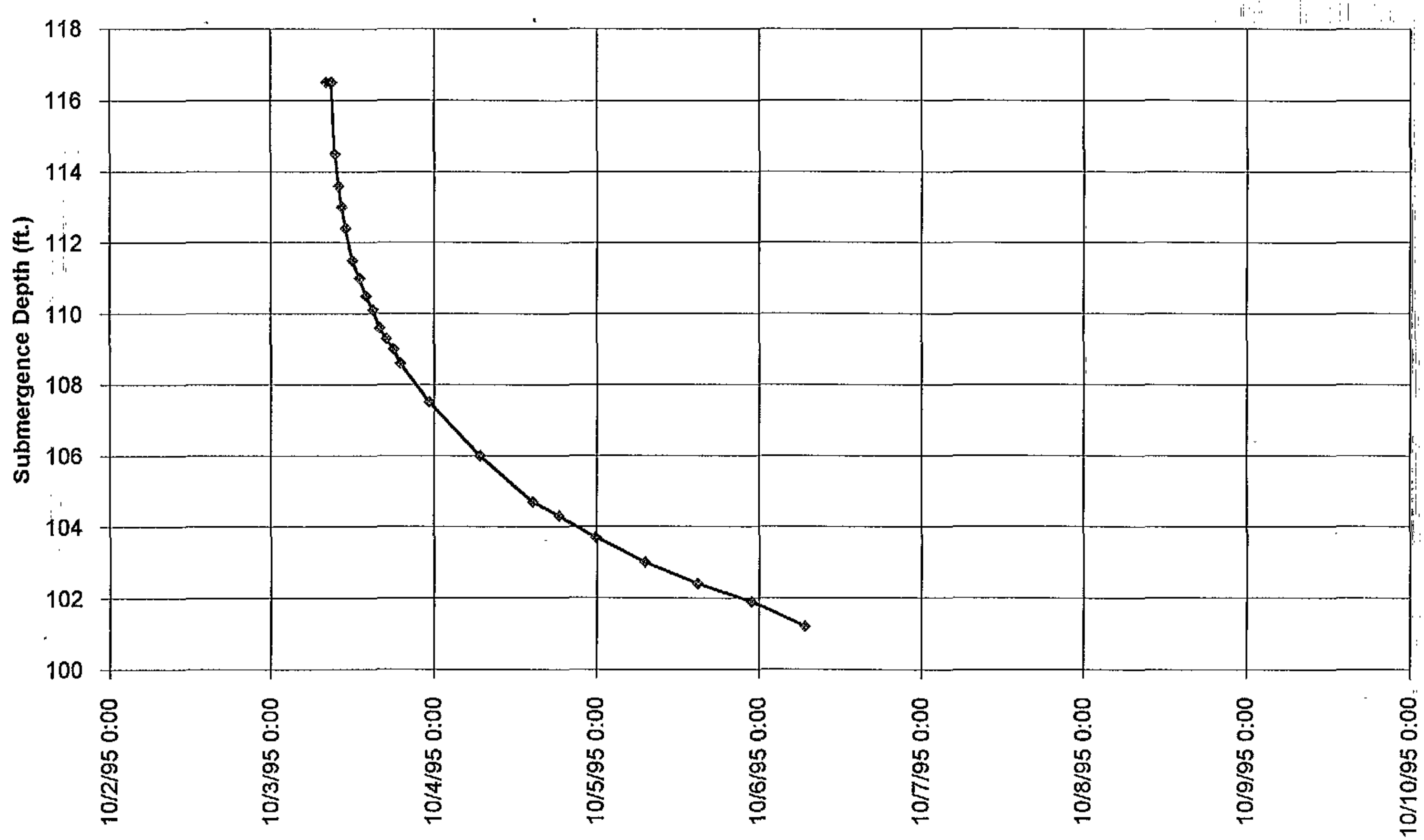
Date Printed: 11/7/95

Pumping Test HIA-2
Production Well HIA-4



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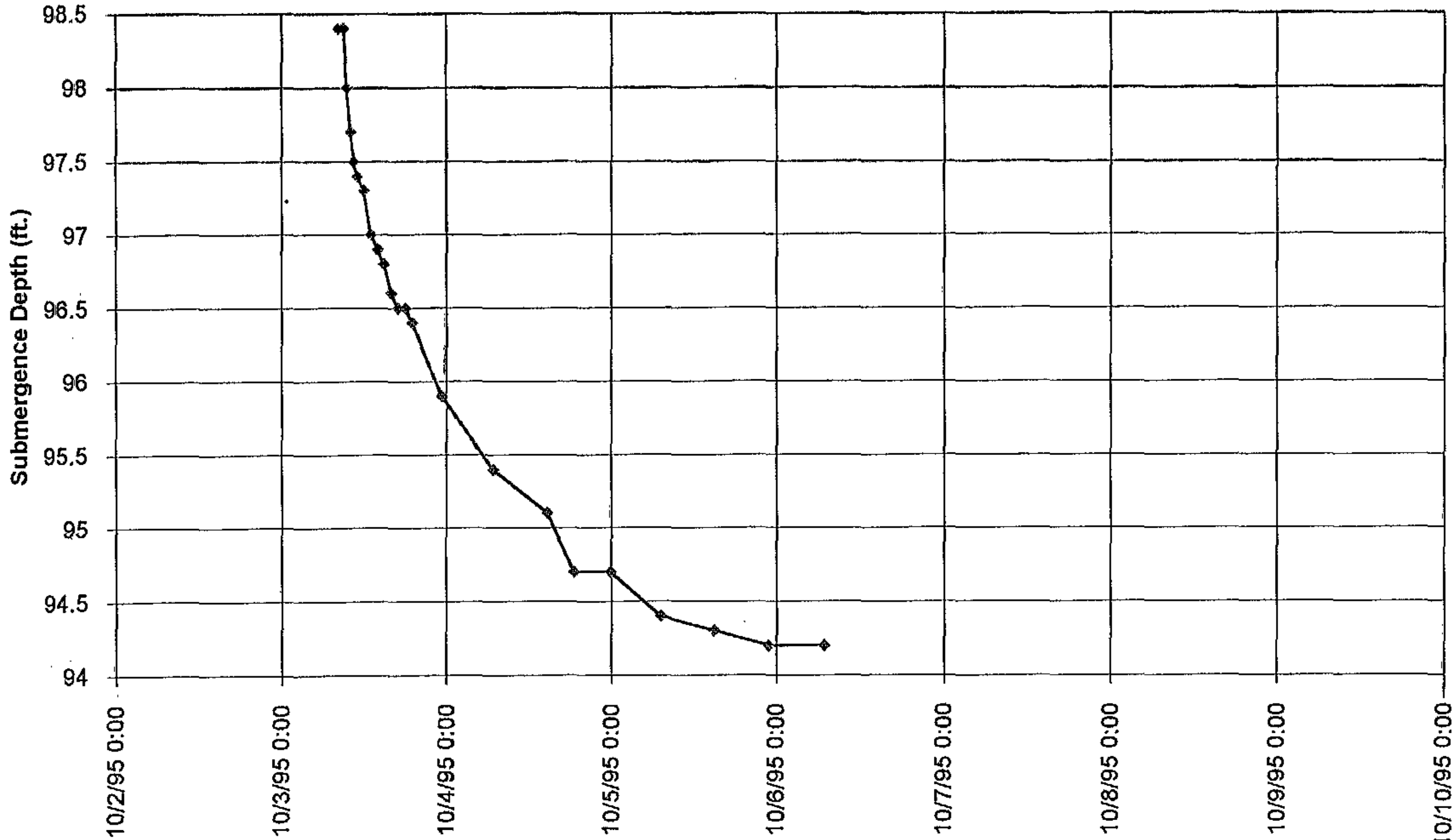
Pumping Test HIA-2
Production Well HIA-5



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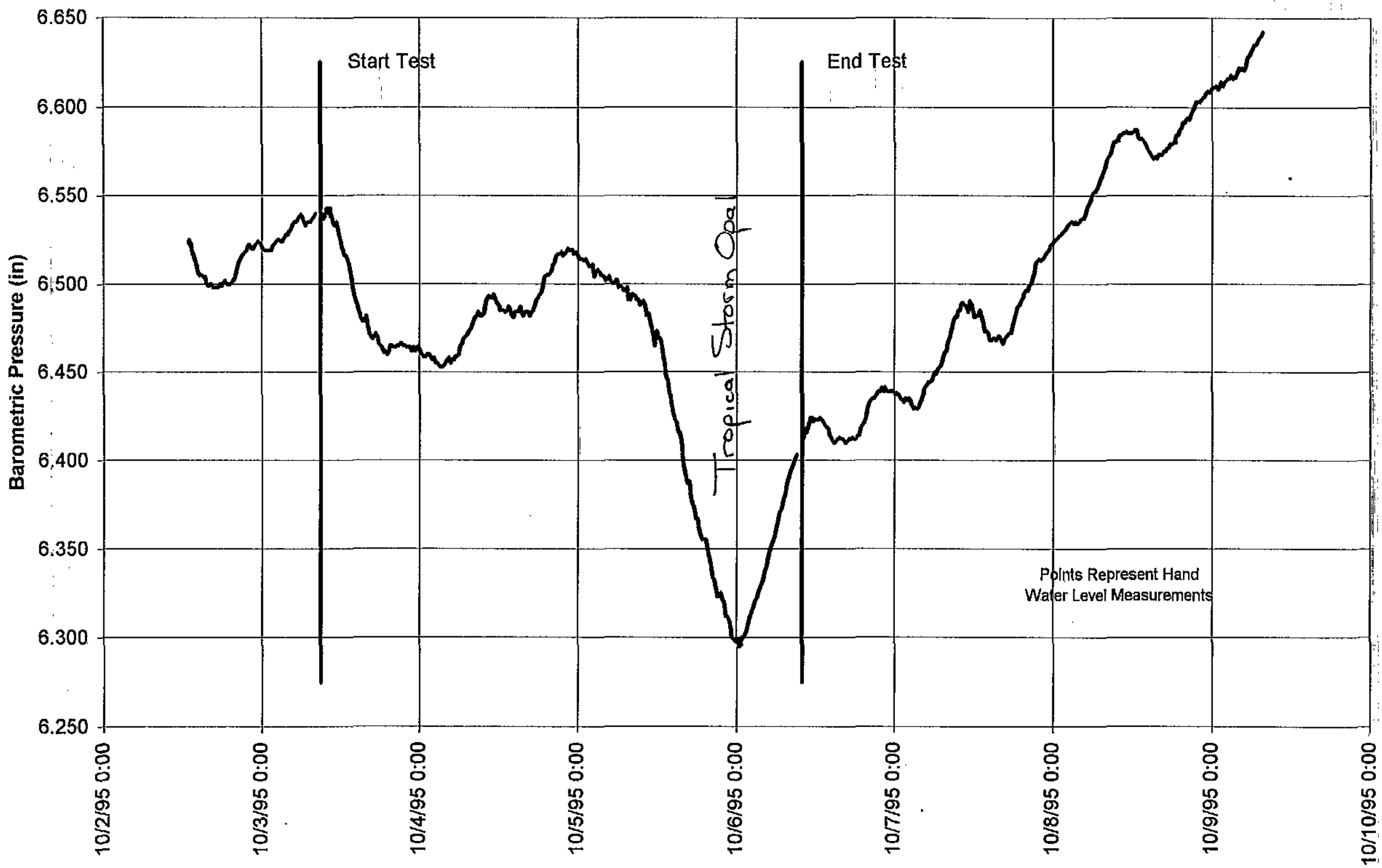

Hydrographs-Pumping Test HIA-9

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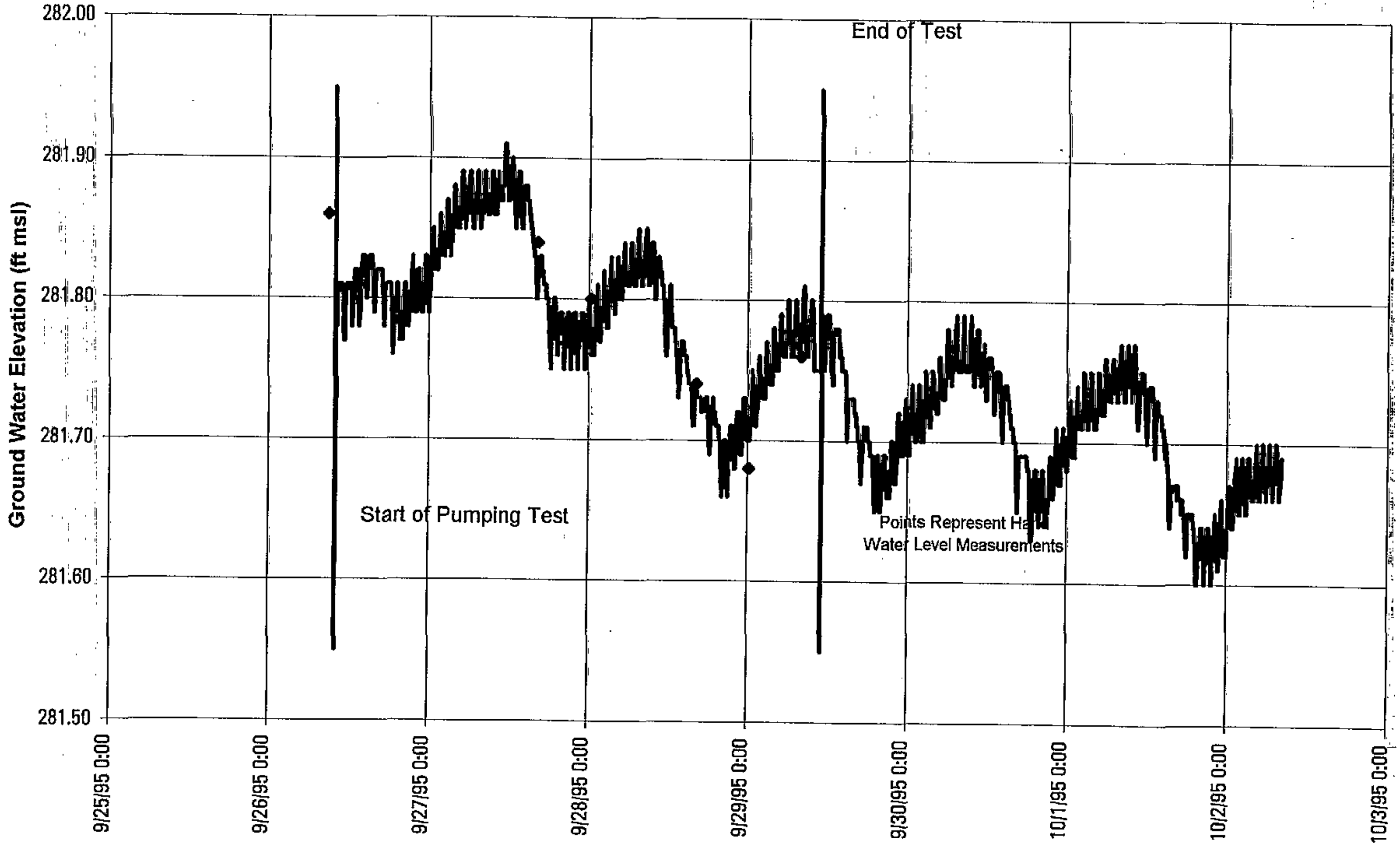
Date Printed: 12/20/95

Pumping Test HIA-9
Observation Well ERM-10I



THE ERM GROUP

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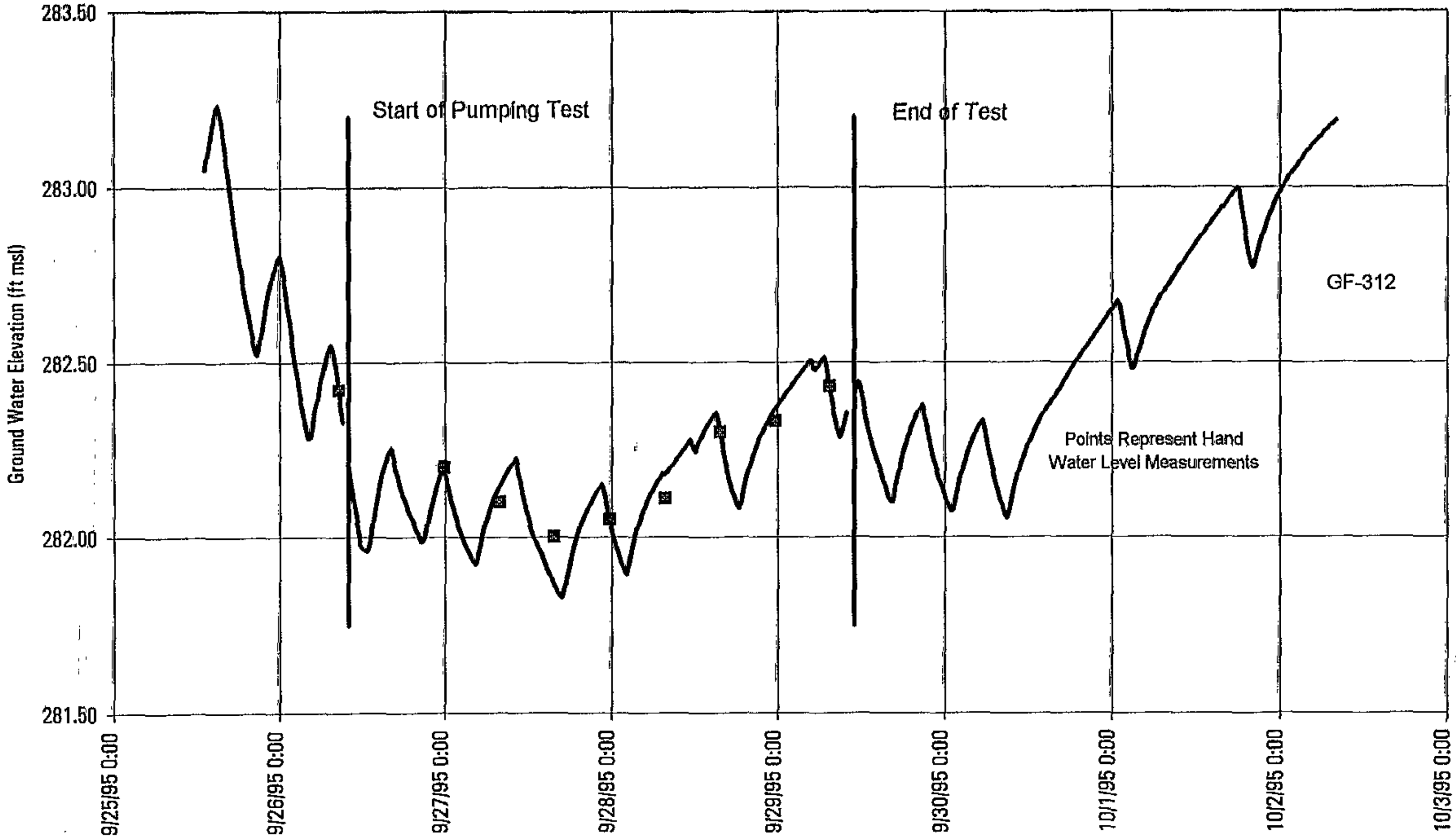
Pumping Test HIA-9
Observation Well GF-312



THE ERM GROUP

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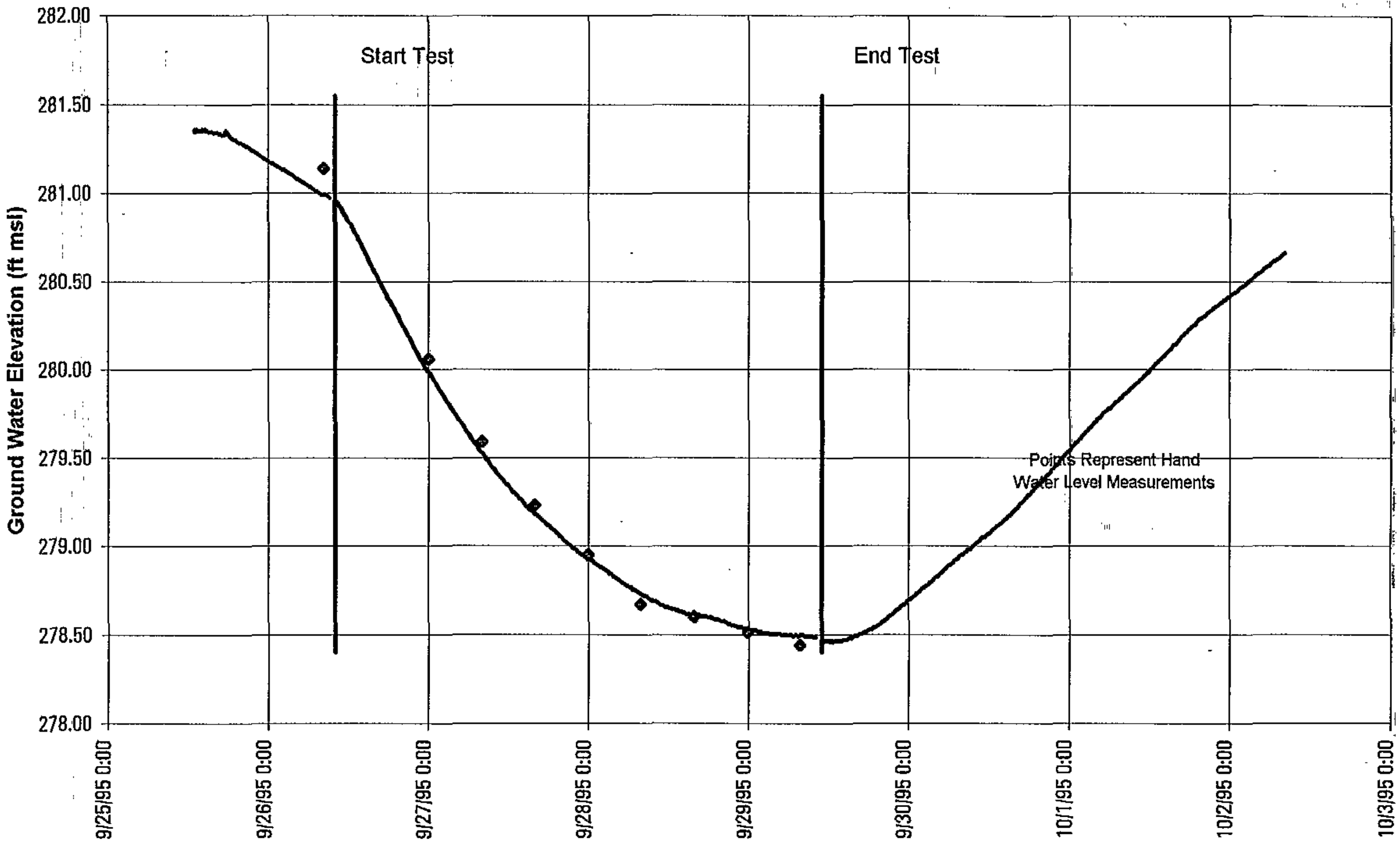

THE ERM GROUP

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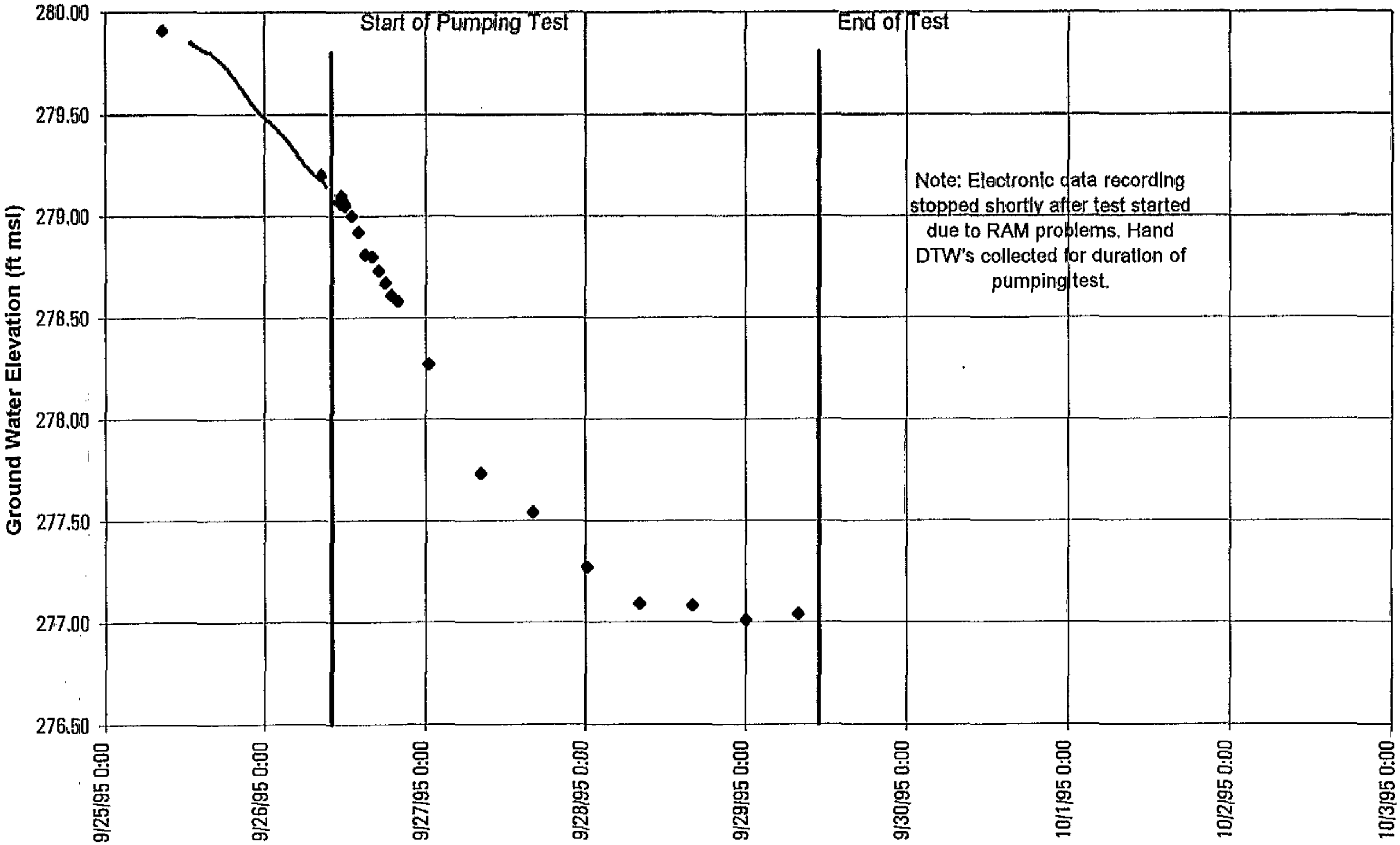
Date Printed: 1

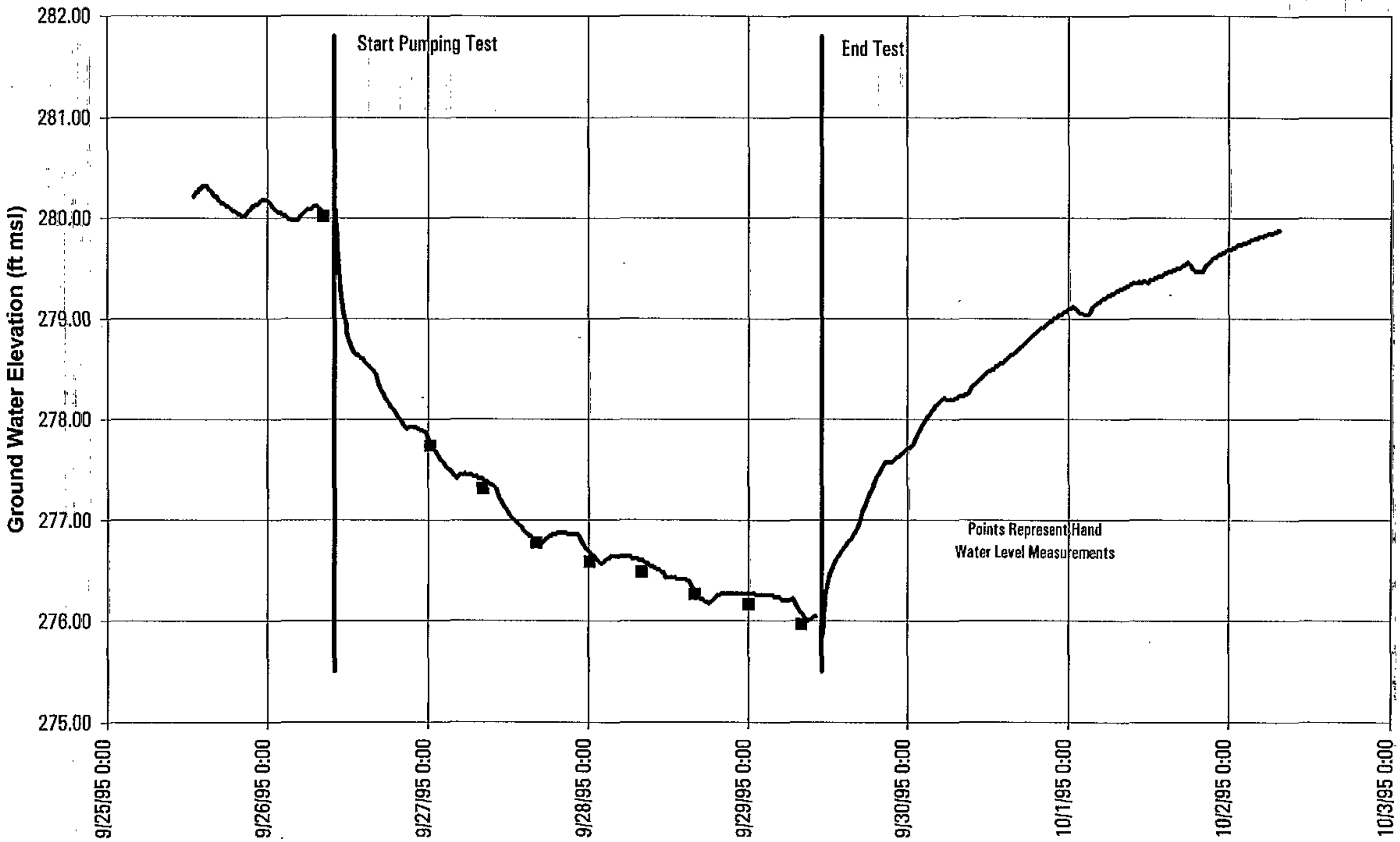
Pumping Test HIA-9
Observation Well ERM-22S



THE ERM GROUP

Filenam _22ID.XLW
Date Printed: 12/20/95

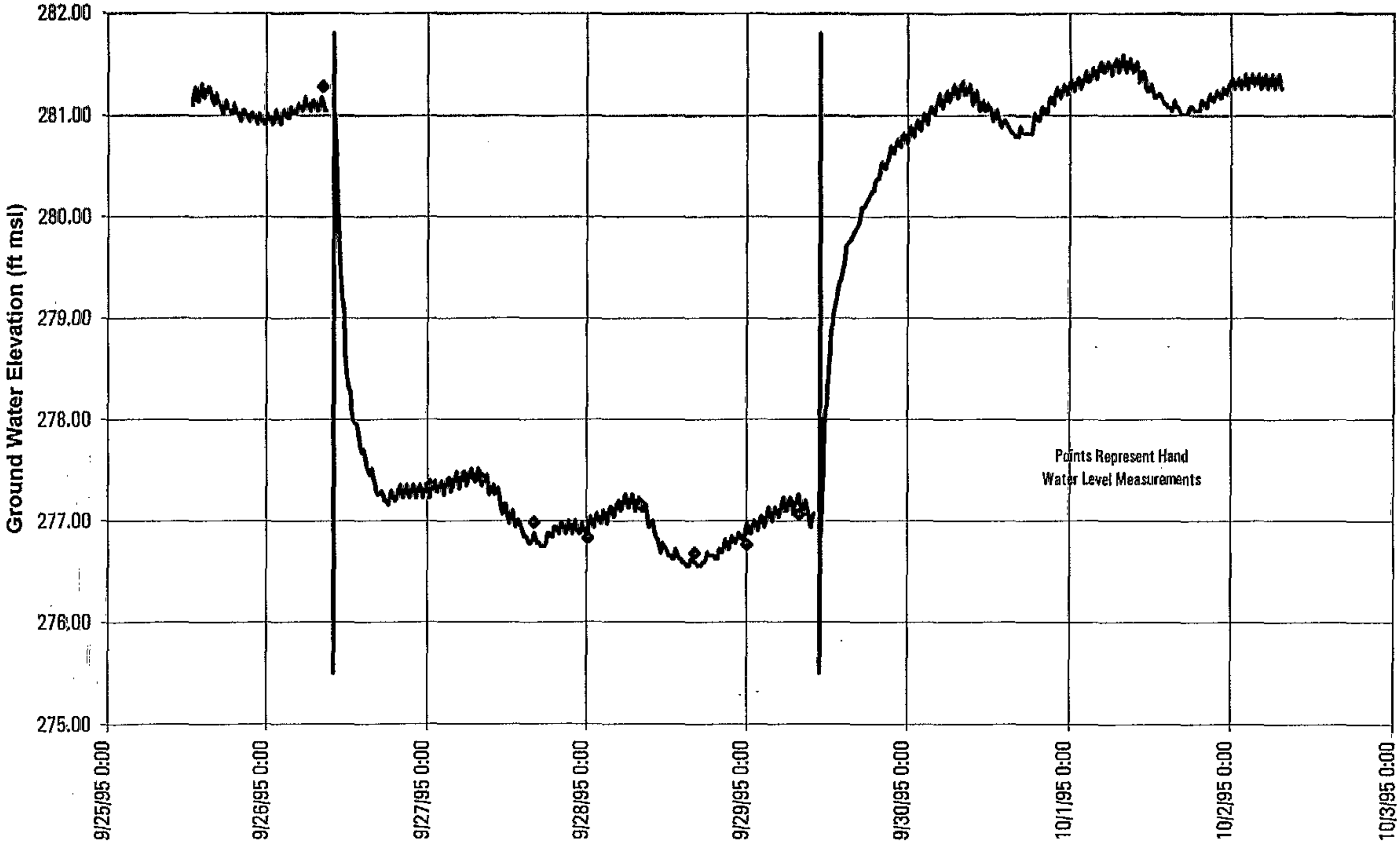
Pumping Test HIA-9
Observation Well ERM-22I



THE ERM GROUP

Filename: REV_220D.XLW
Date Printed: 12/20/95

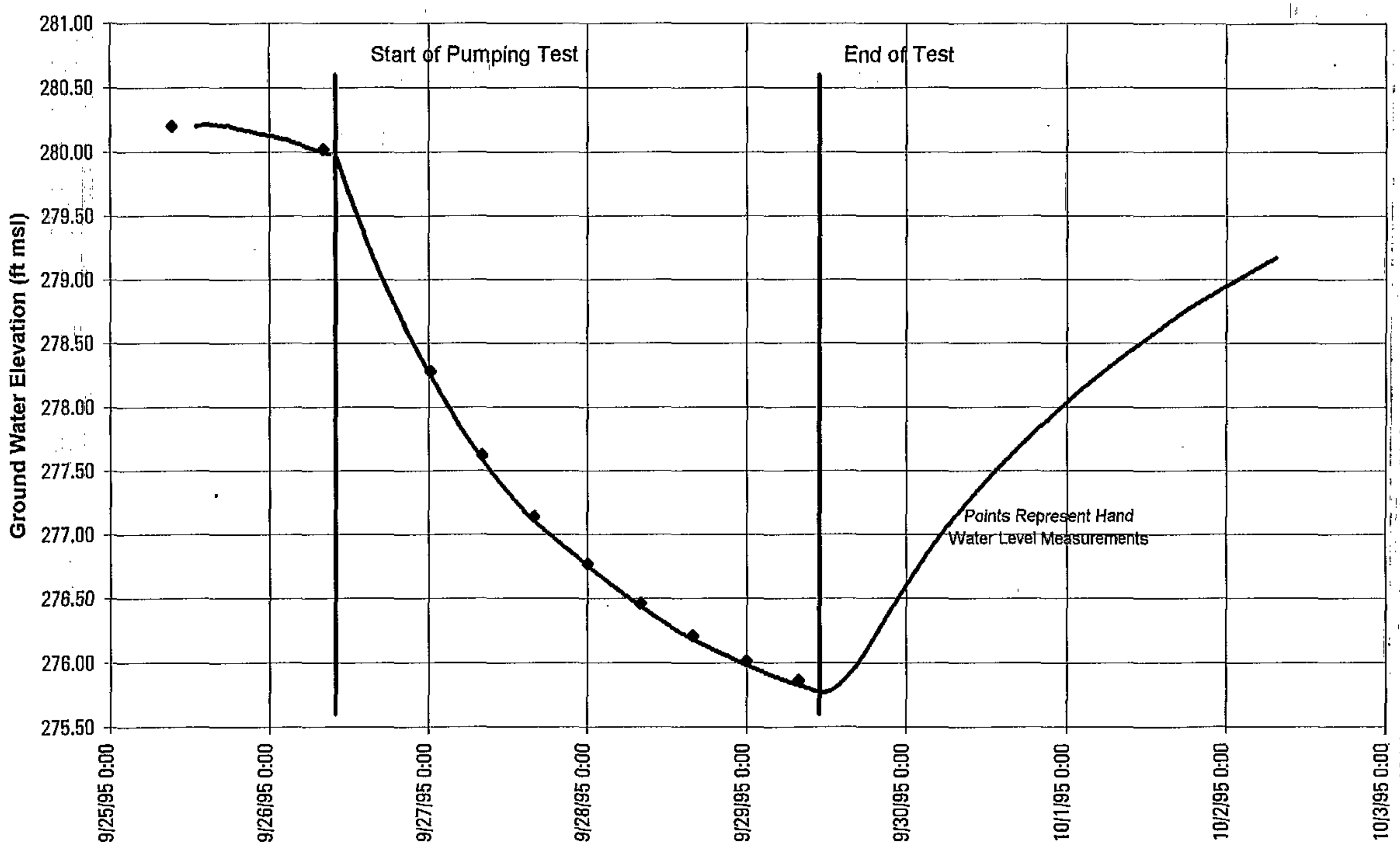
Pumping Test HIA-9
Observation Wells ERM-22D



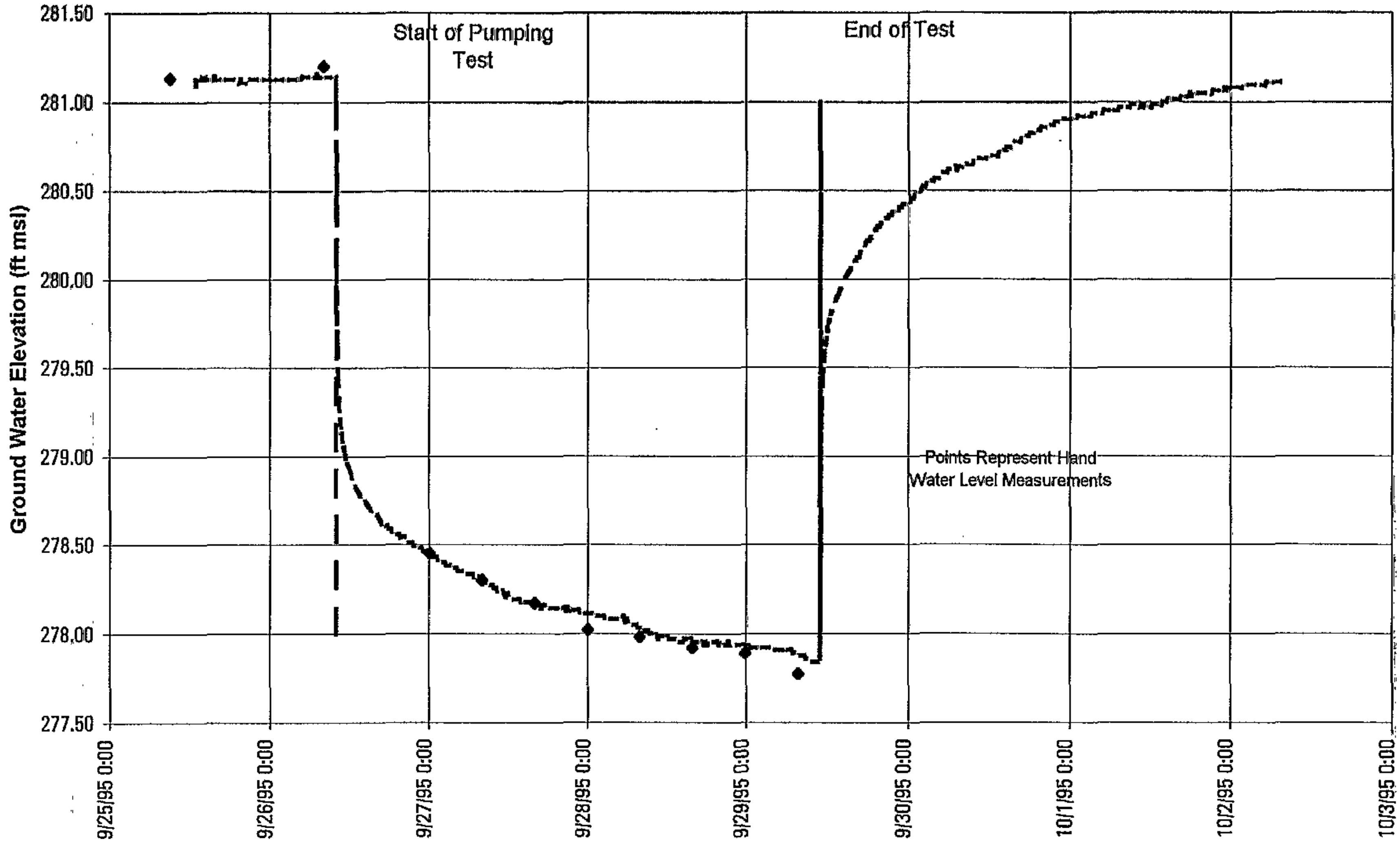
THE ERM GROUP

Filenam[illegible]9_21S.XLW
Date Printed: 12/20/95

Pumping Test HIA-9
Observation Well ERM-21S

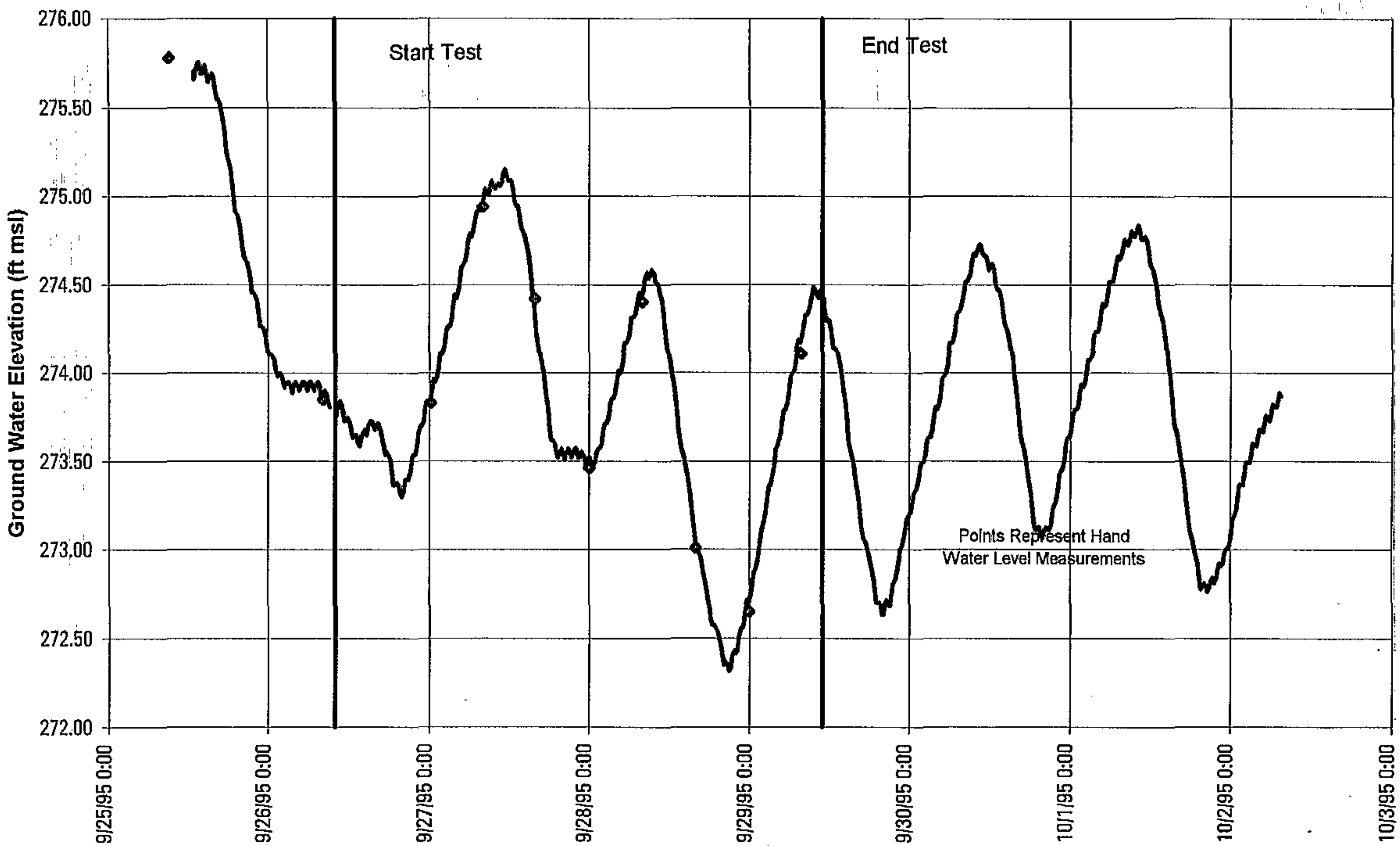


Pumping Test HIA-9
Observation Well ERM-21I



Filename: _21D.XLW
Date Printed: 12/20/95

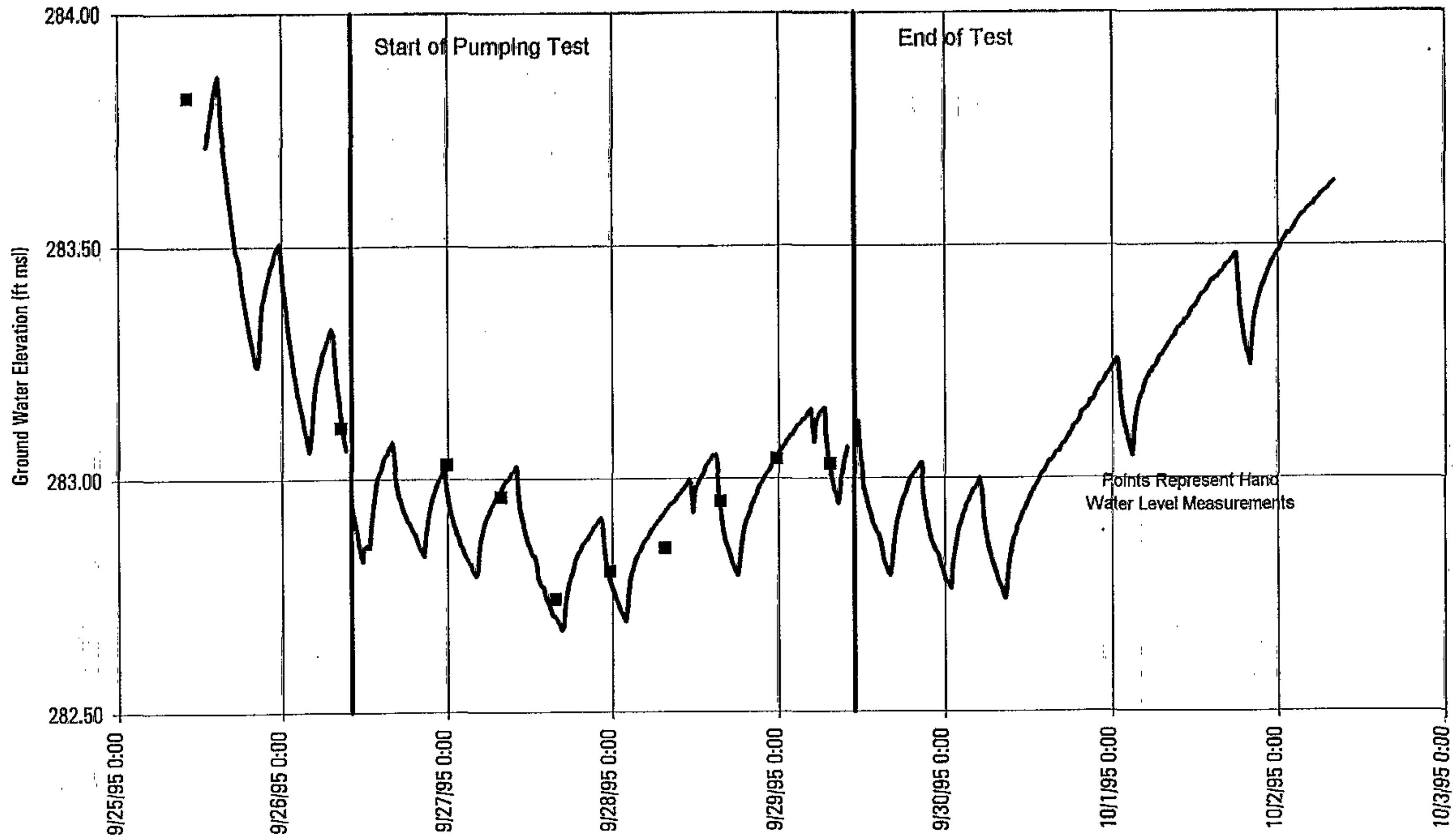
Pumping Test HIA-9
Observation Well ERM-21D



THE ERM GROUP

Filename: H-9_2312.XLW
Date Printed: 12/20/95

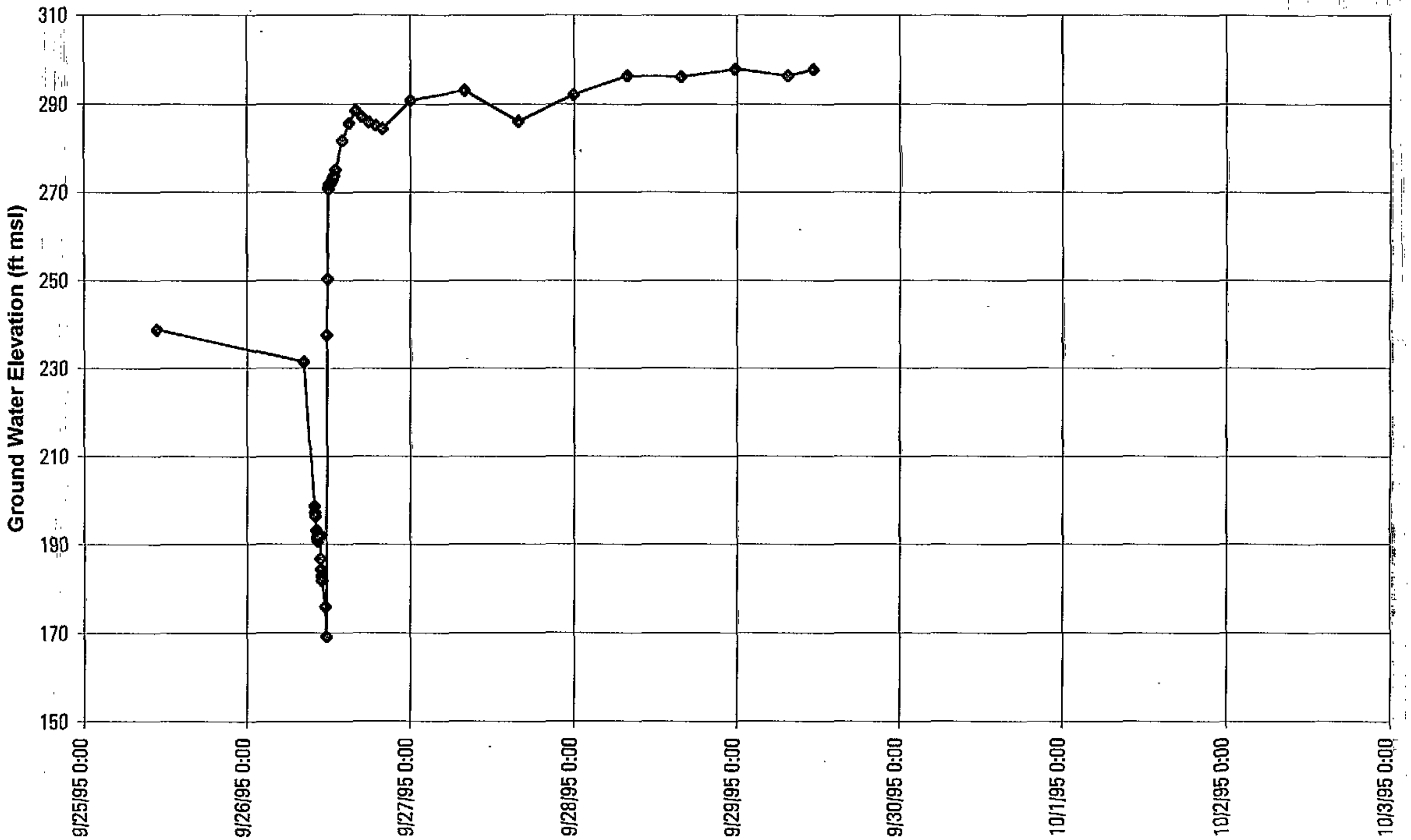
Pumping Test HIA-9
Observation Well GF-212



THE ERM GROUP

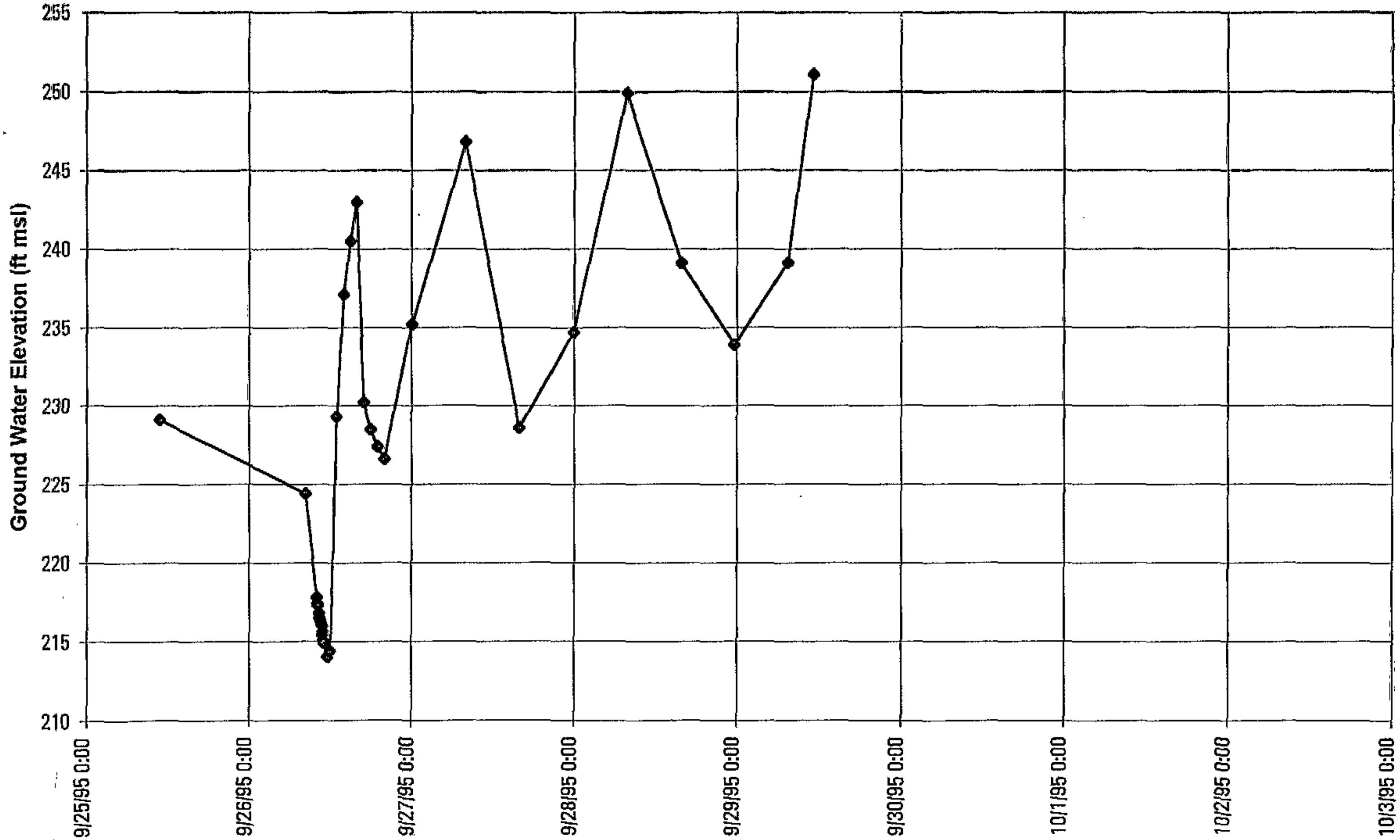
Filename: _SUBM.XLW
Date Printed: 12/20/95

Pumping Test HIA-9
Production Well HIA-6



Filename: H9_SDBM.XLW
Date Printed: 12/20/95

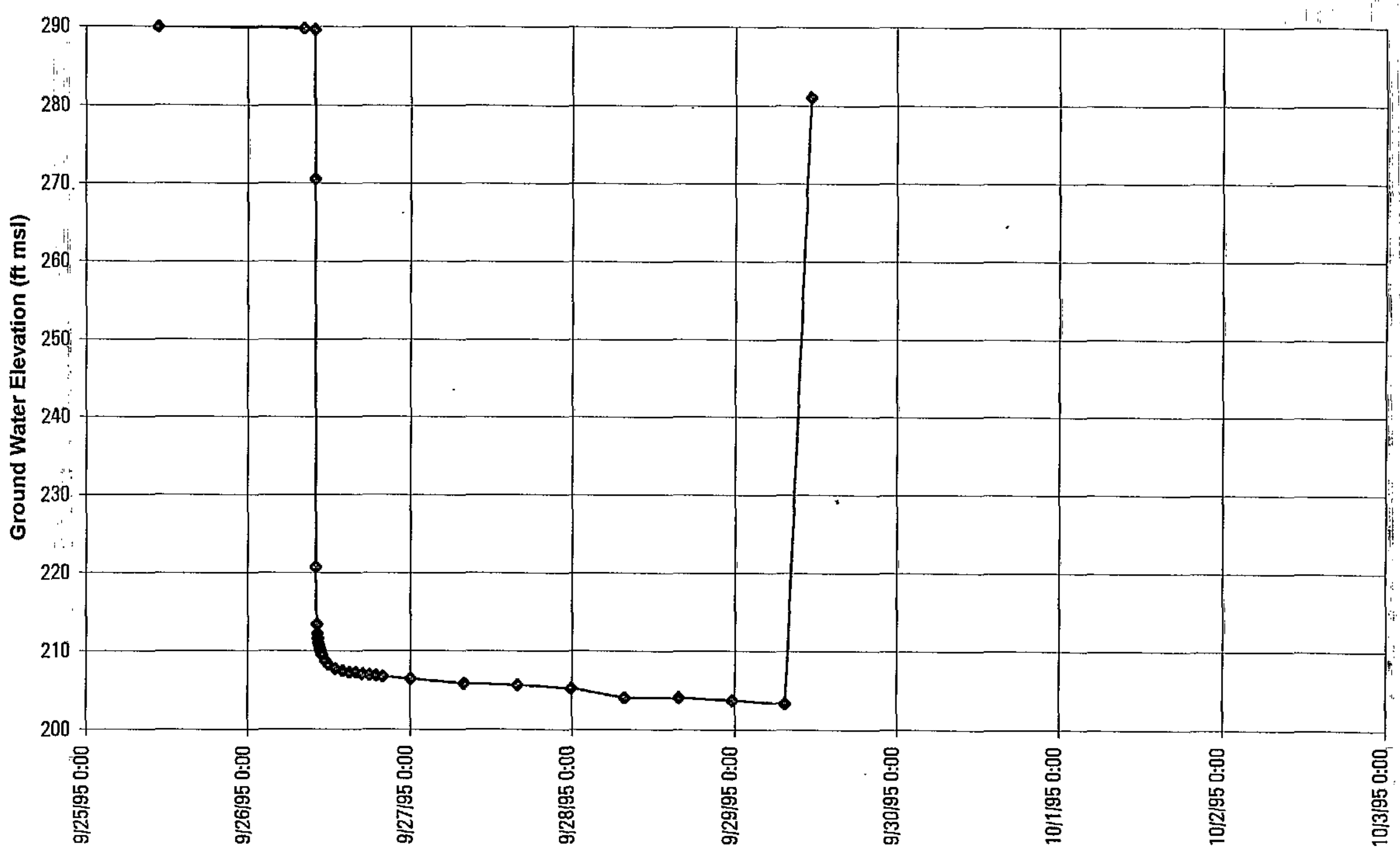
Pumping Test HIA-9
Production Well HIA-12



THE ERM GROUP

Filename: _SUBM.XLW
Date Printed: 12/20/95

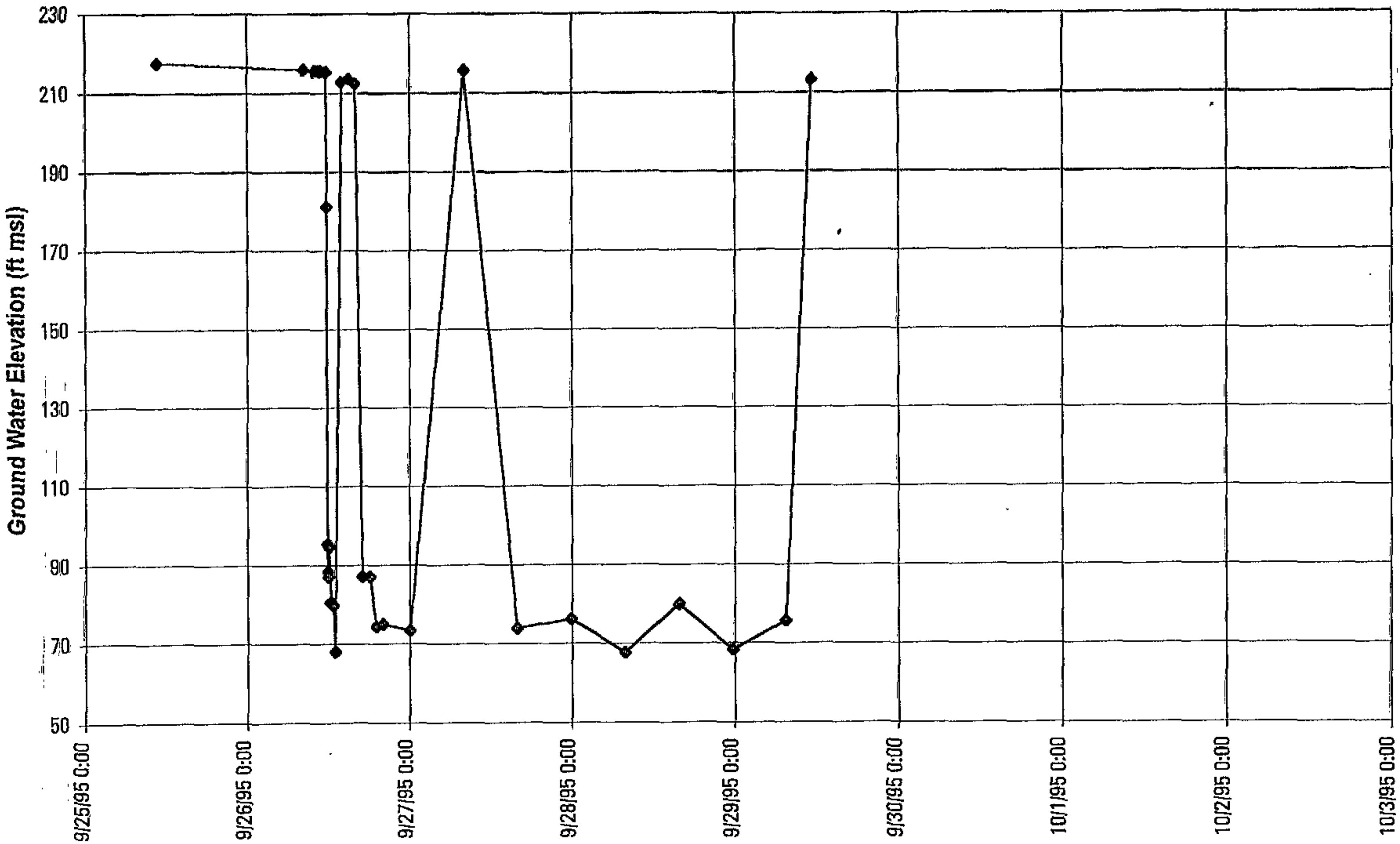
Pumping Test HIA-9
Production Well HIA-9



THE ERM GROUP

Filename: H9_SUBM.XLW
Date Printed: 12/20/95

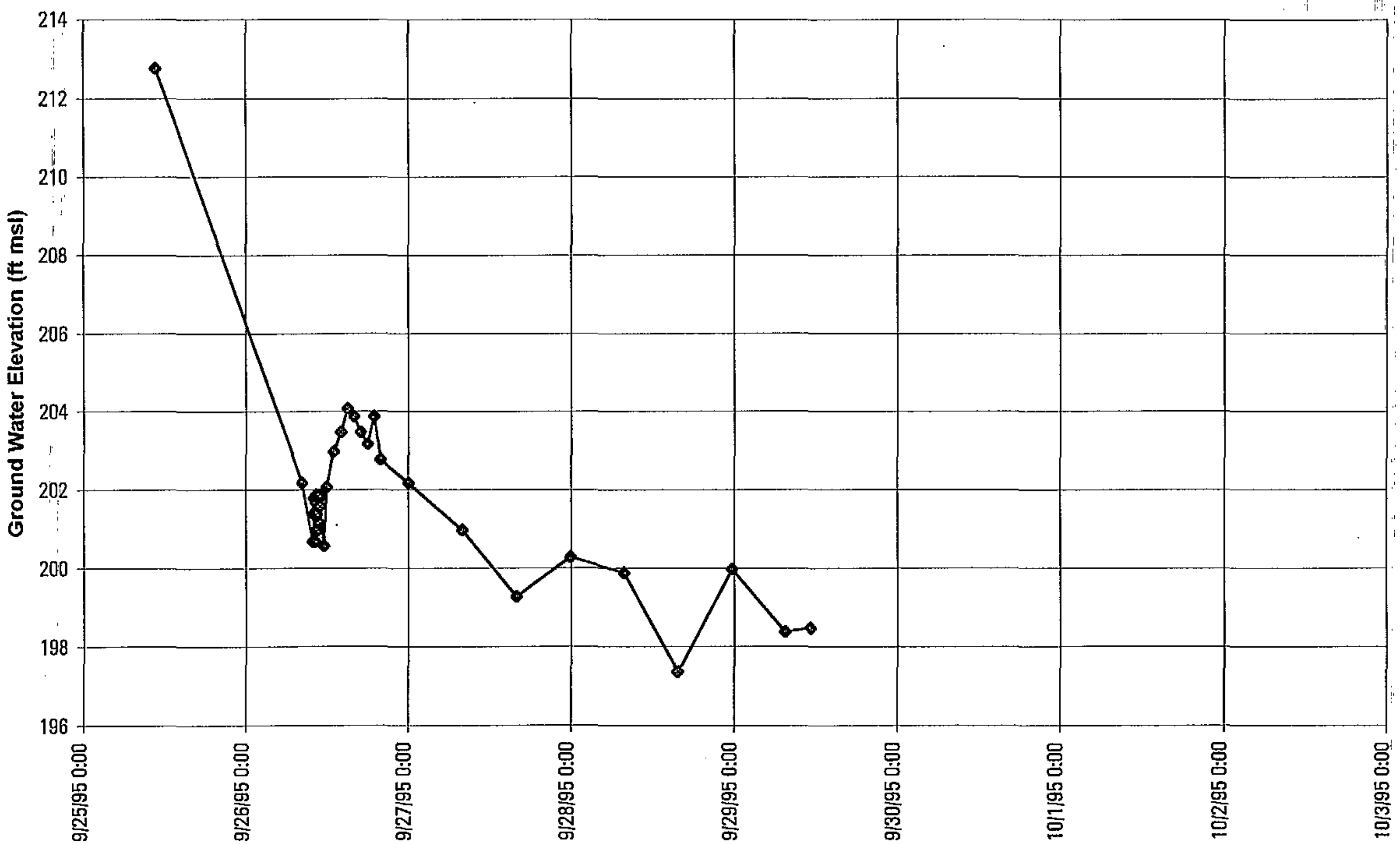
Pumping Test HIA-9
Production Well HIA-13



THE ERM GROUP

Filename: H[illegible]_SUBM.XLW
Date Printed: 12/20/95

Pumping Test HIA-9
Production Well HIA-11



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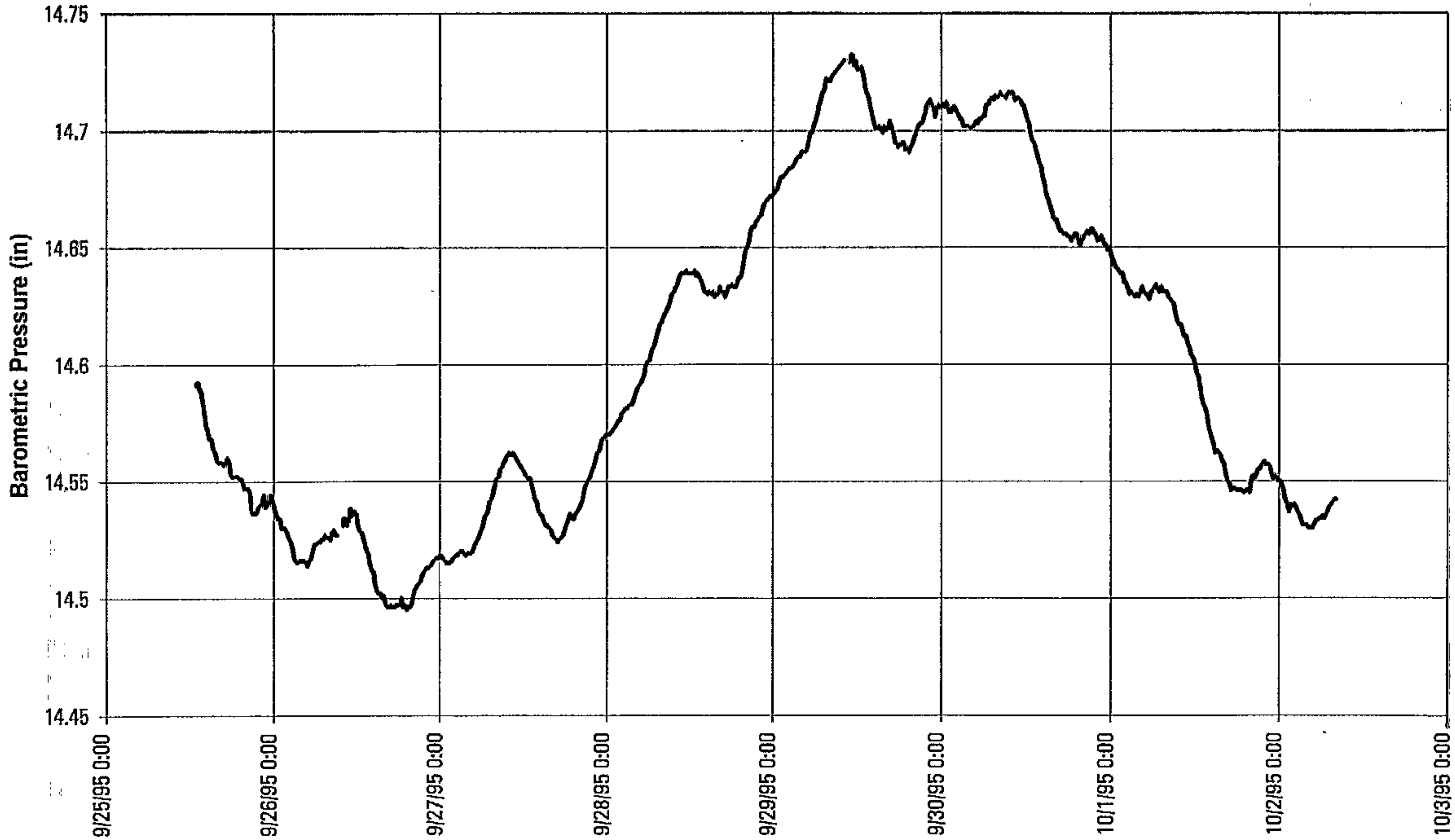
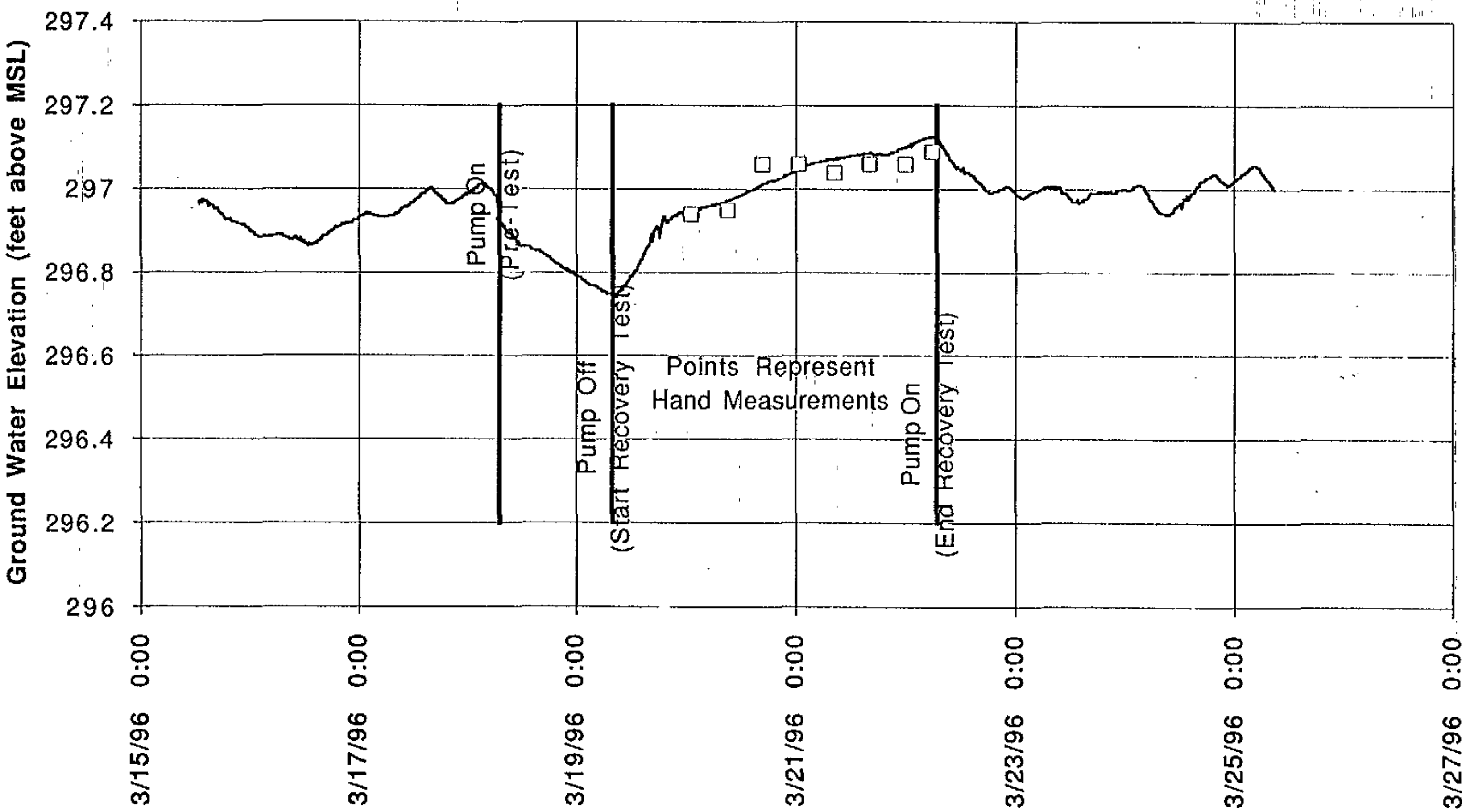
Pumping Test HIA-9
Barometric Pressure



Arithmetic Plots-Recovery Test HIA-13

File Name: [RFW3]Ar[illegible]RFW3
Date Printed: 4/9/96

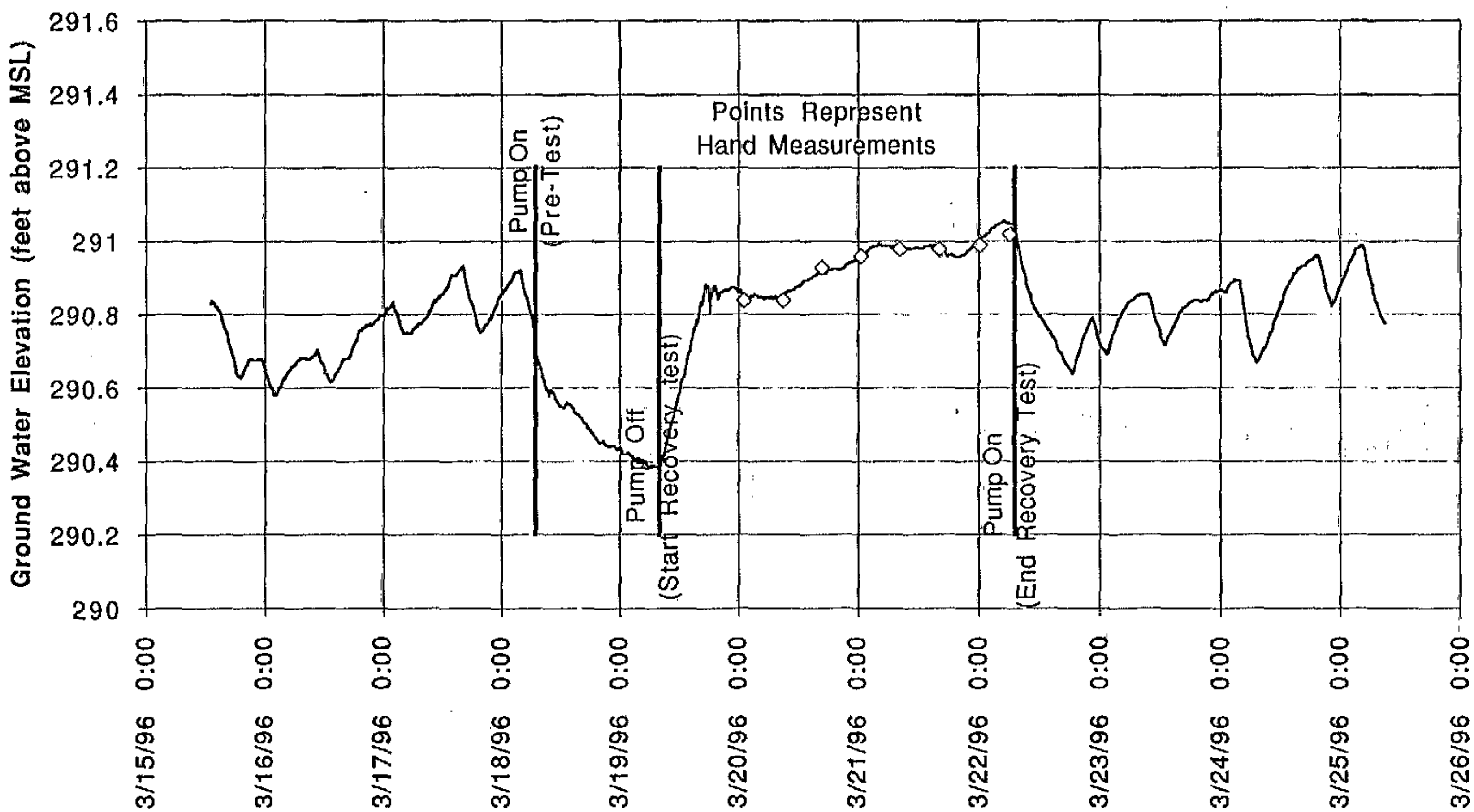
Recovery Test HIA-13
Observation Well RFW-3
Data Logger Measurements



THE ERM GROUP

File Name: [23S-23D]Arith. - 23S
Date Printed: 4/9/96

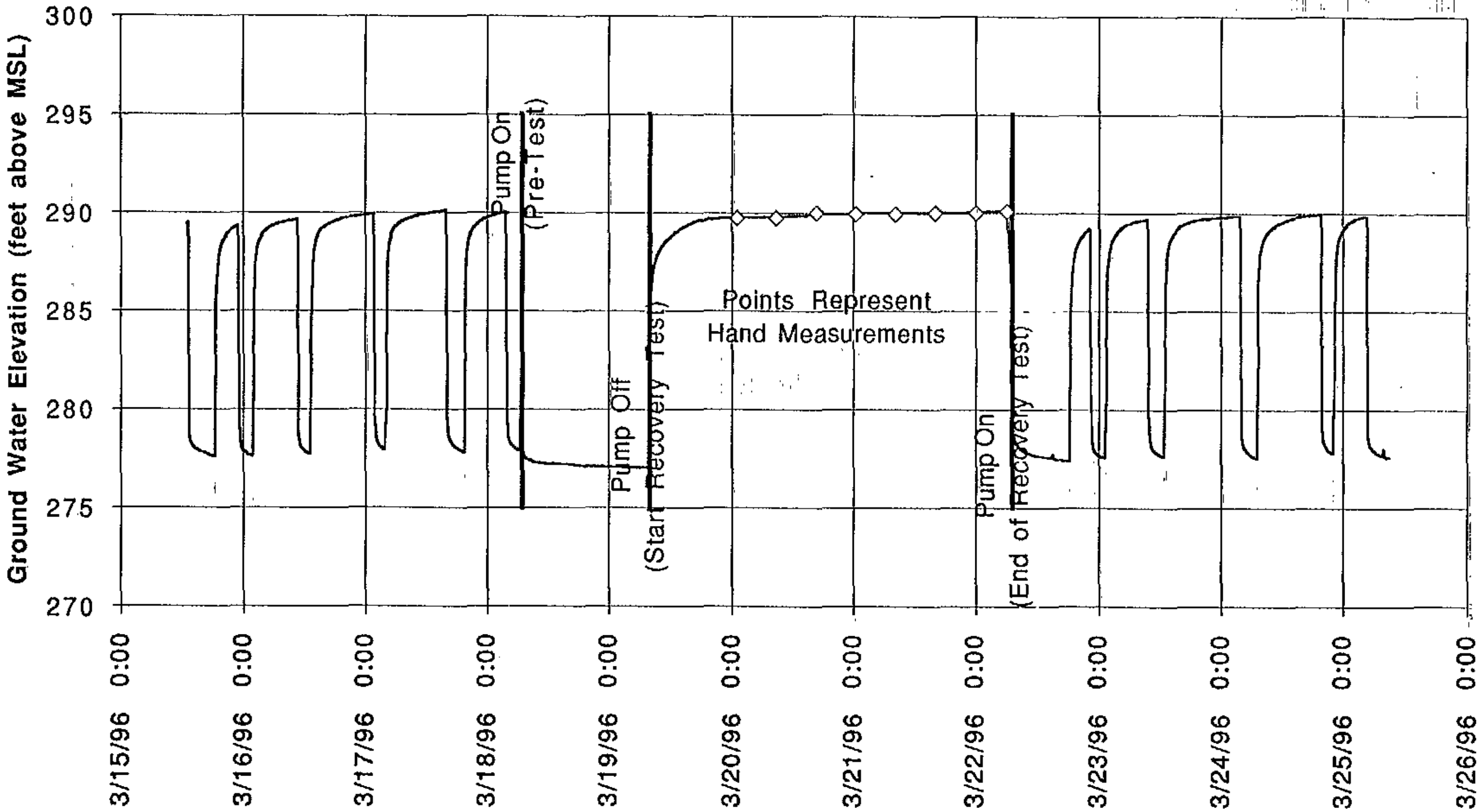
Recovery Test HIA-13
Observation Well ERM-23S
Data Logger Measurements



THE ERM GROUP

File Name: [231-Barom.] ... - 231
Date Printed: 4/9/96

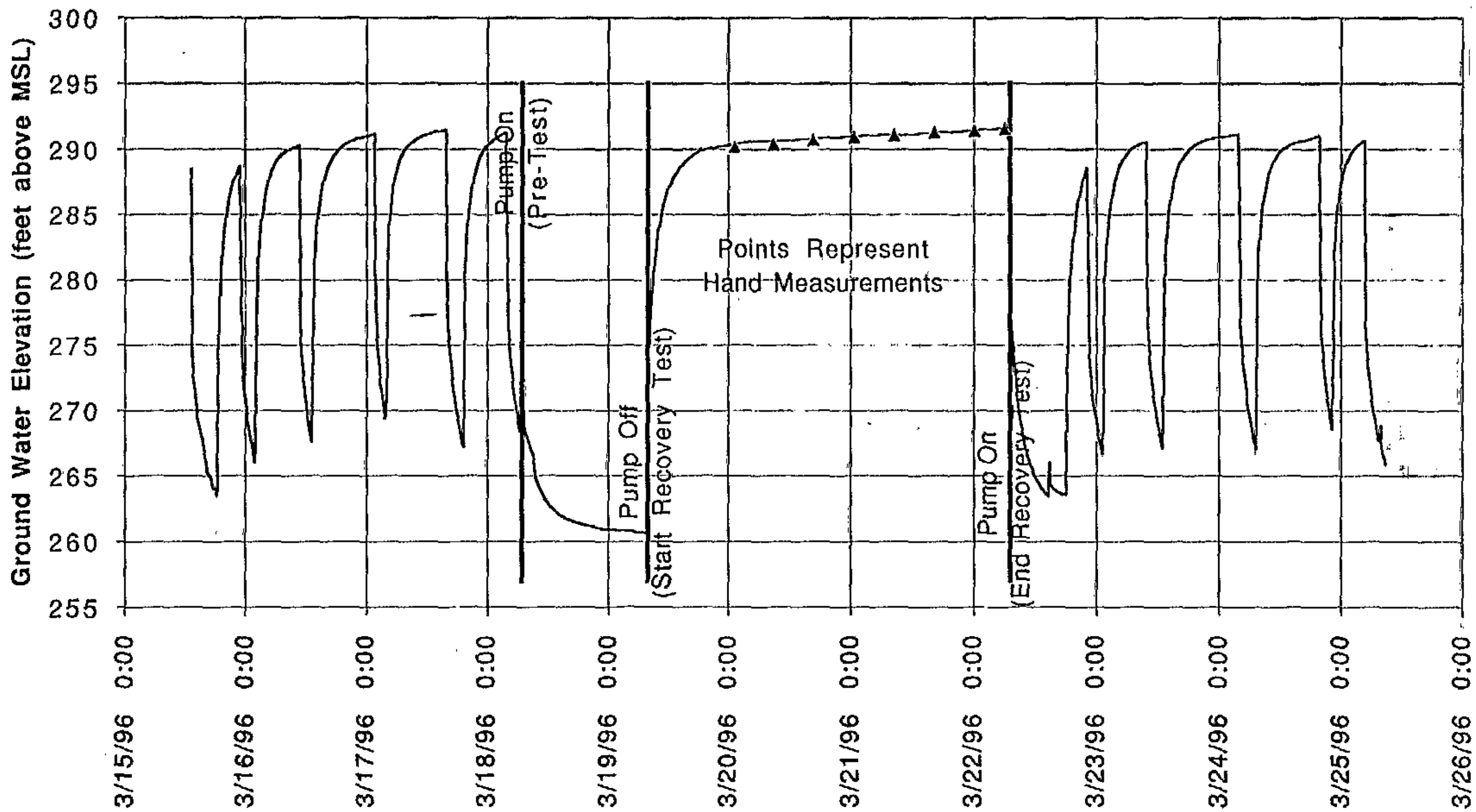
Recovery Test HIA-13
Observation Well ERM-231
Data Logger Measurements



THE ERM GROUP

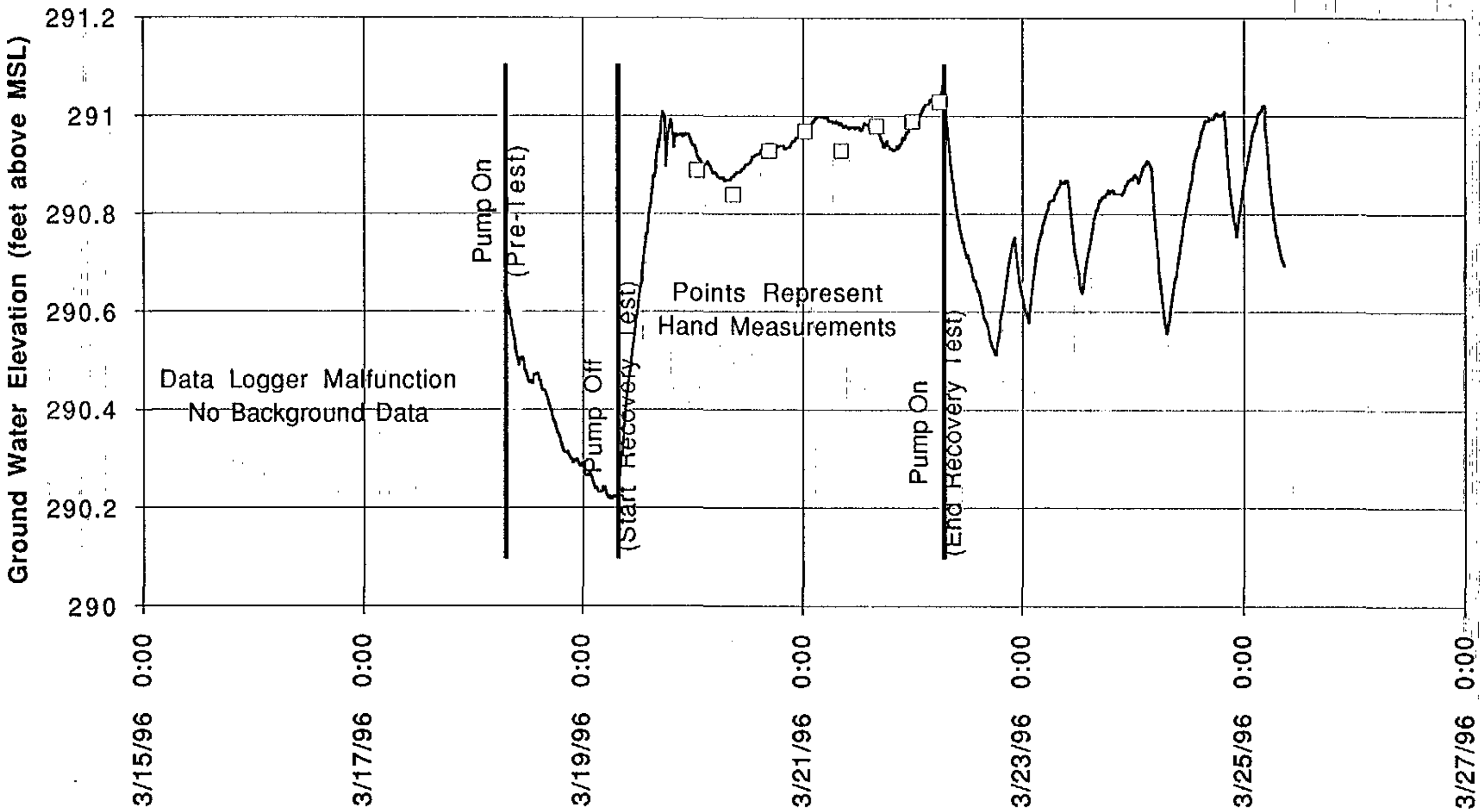
File Name: [23S-23D]Arith. - 23D
Date Printed: 4/9/96

Recovery Test HIA-13
Observation Well ERM-23D
Data Logger Measurements

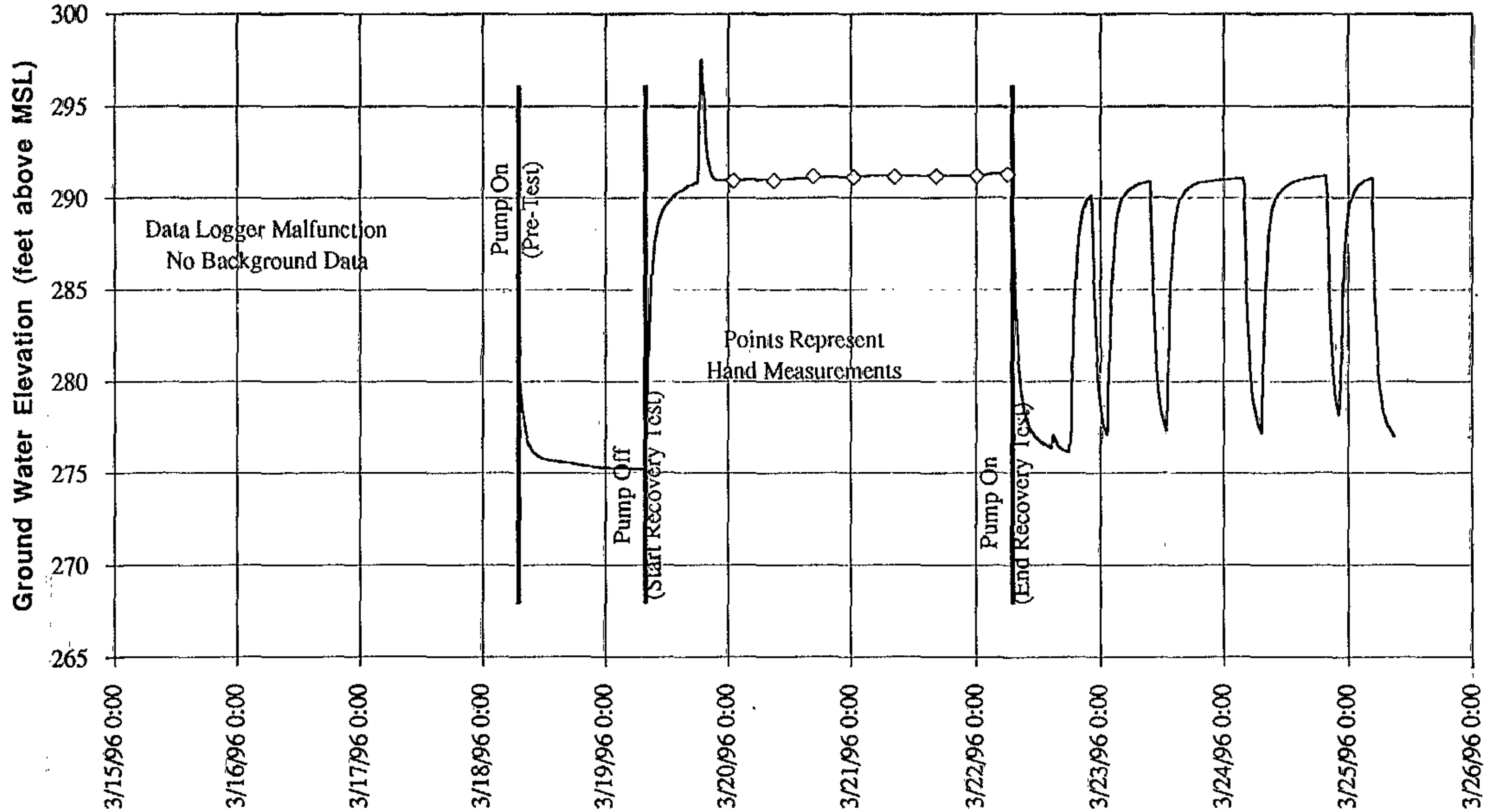


THE ERM GROUP

Recovery Test HIA-13
Observation Well ERM-24S
Data Logger Measurements

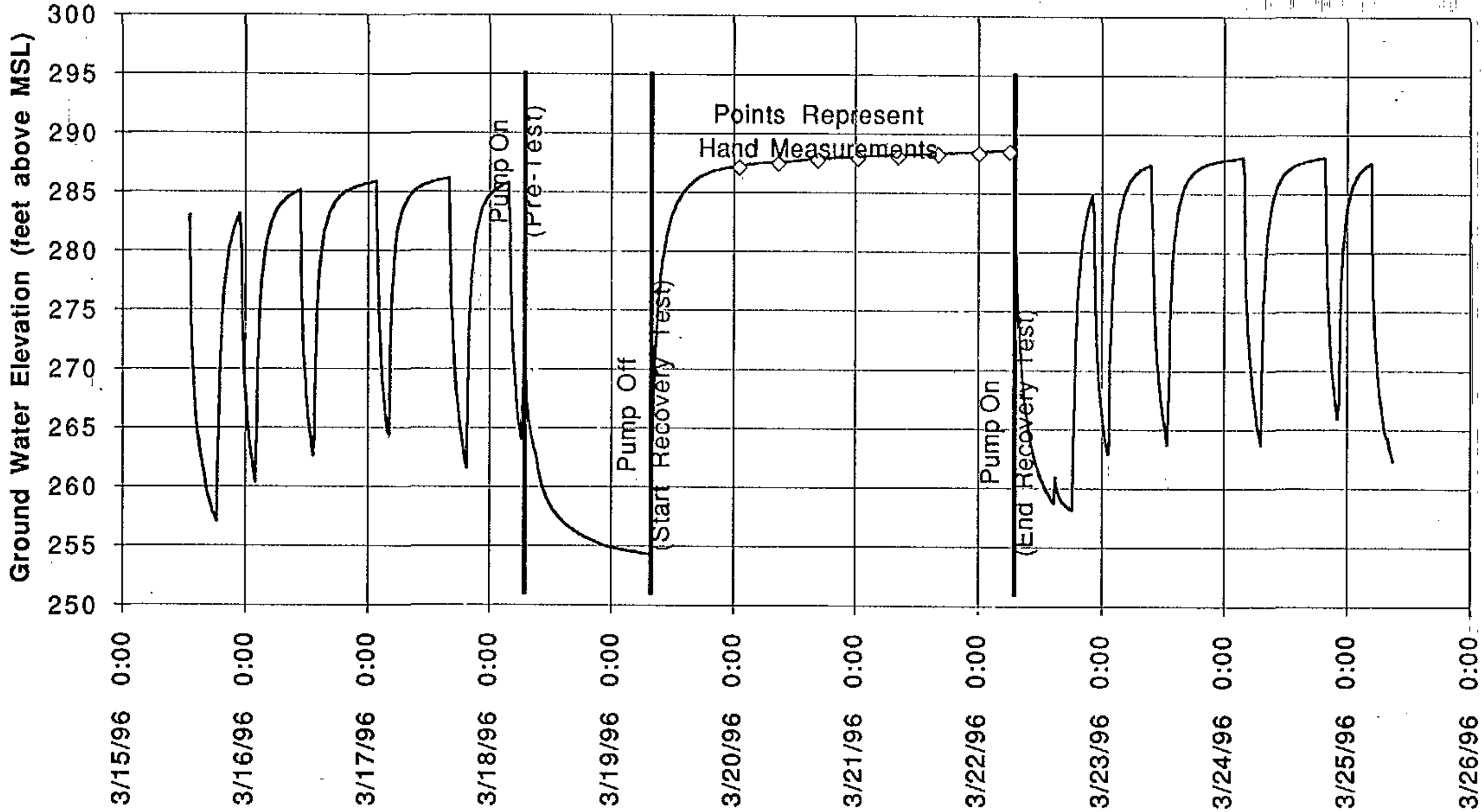


Recovery Test HIA-13
Observation Well ERM-241
Data Logger Measurements



File Name: [24I-24D]A - 24D
Date Printed: 4/9/96

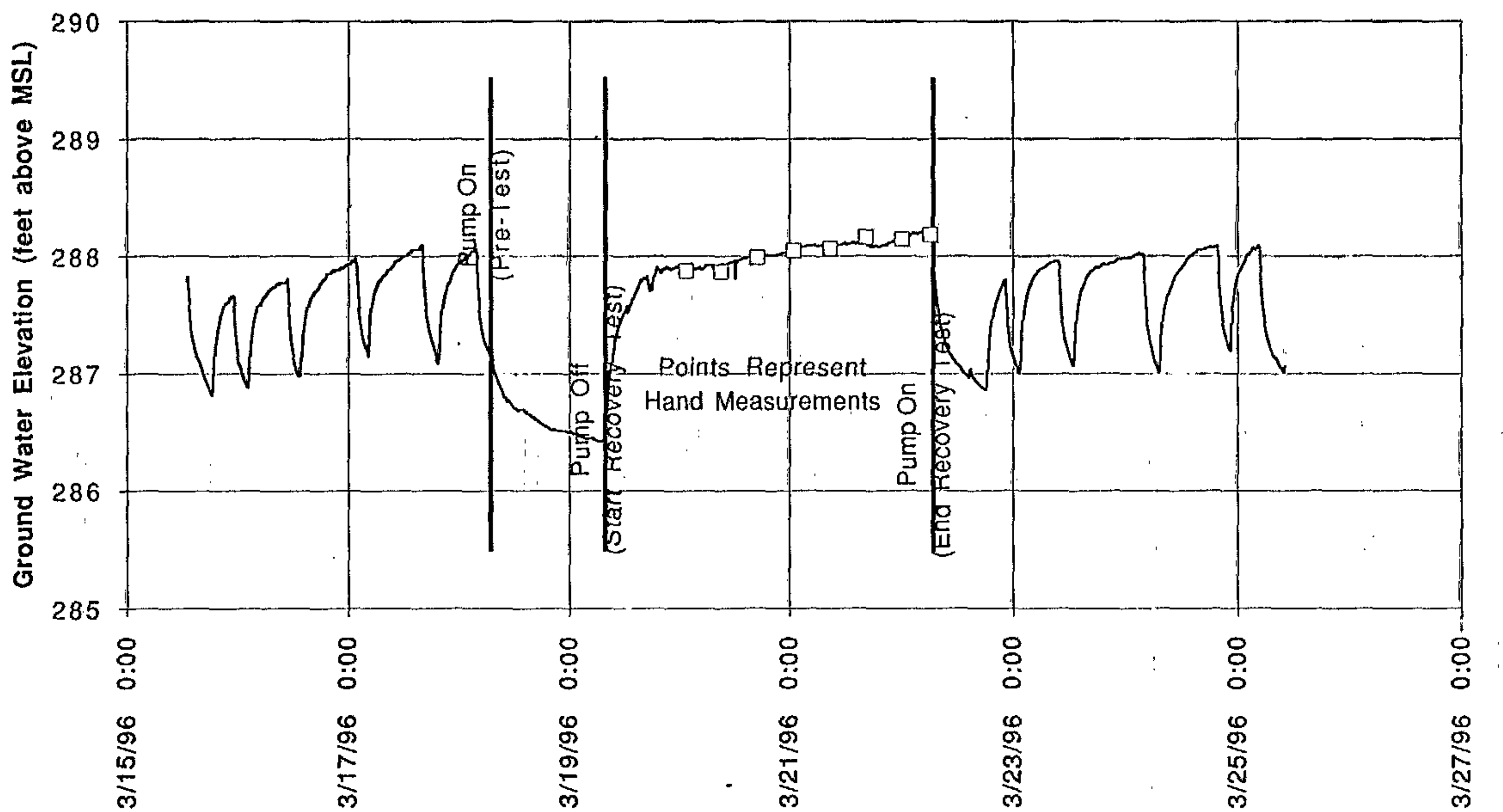
Recovery Test HIA-13
Observation Well ERM-24D
Data Logger Measurements



THE ERM GROUP

File Name: [32I]Arith. - 32I
Date Printed: 4/9/96

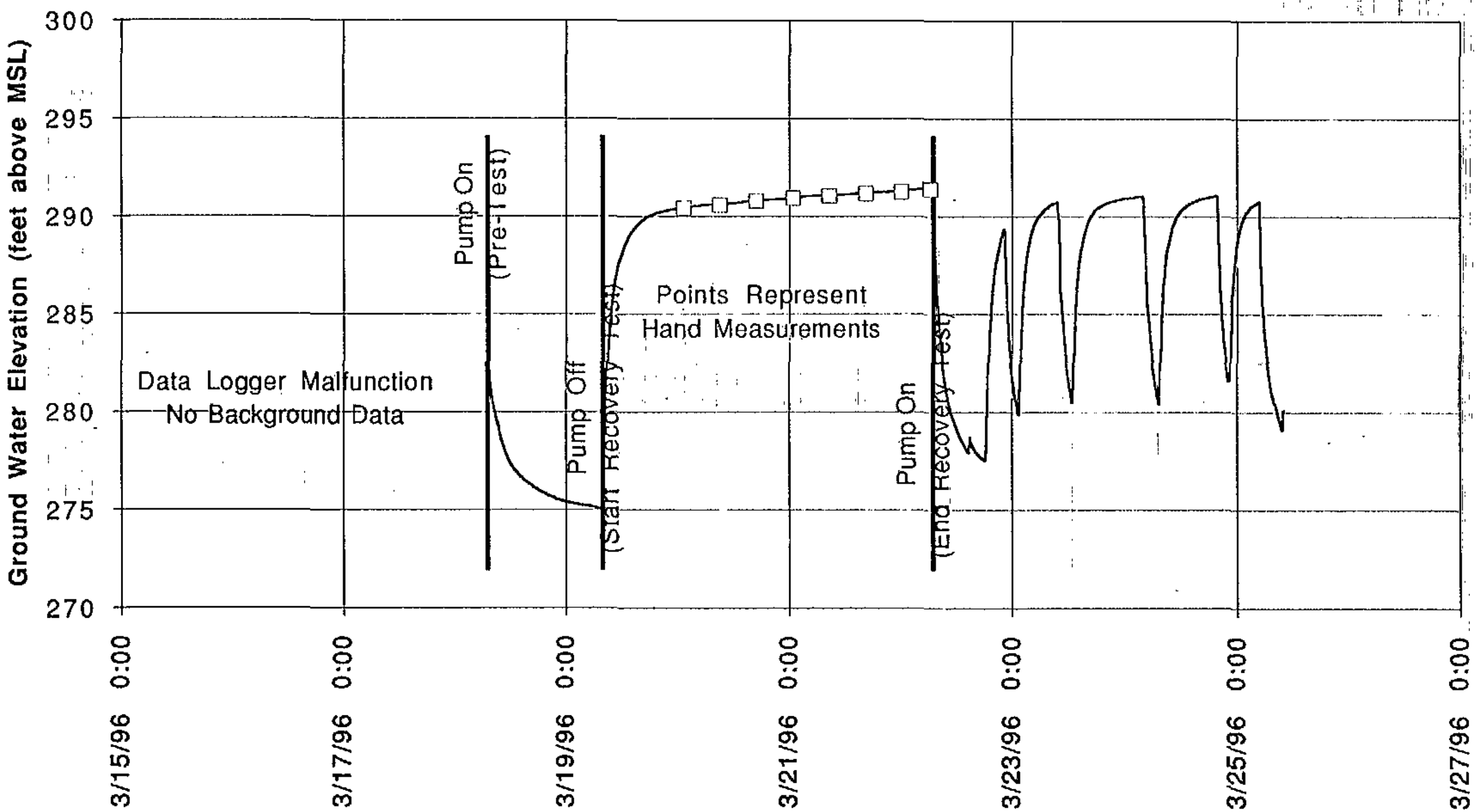
Recovery Test HIA-13
Observation Well ERM-32I
Data Logger Measurements



THE ERM GROUP

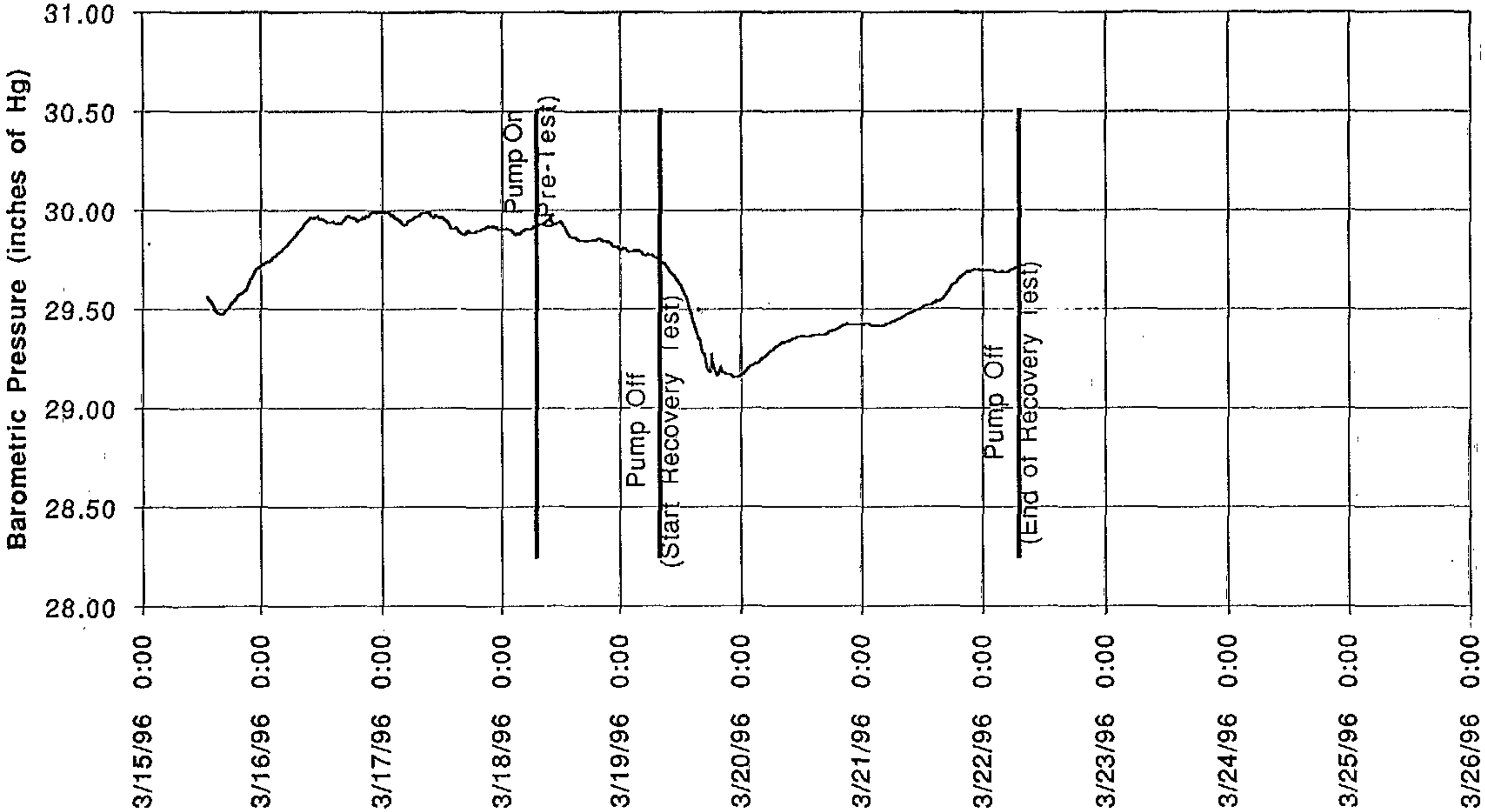
File Name: [32D][illegible] - 32D
Date Printed: 4/9/96

Recovery Test HIA-13
Observation Well ERM-32D
Data Logger Measurements

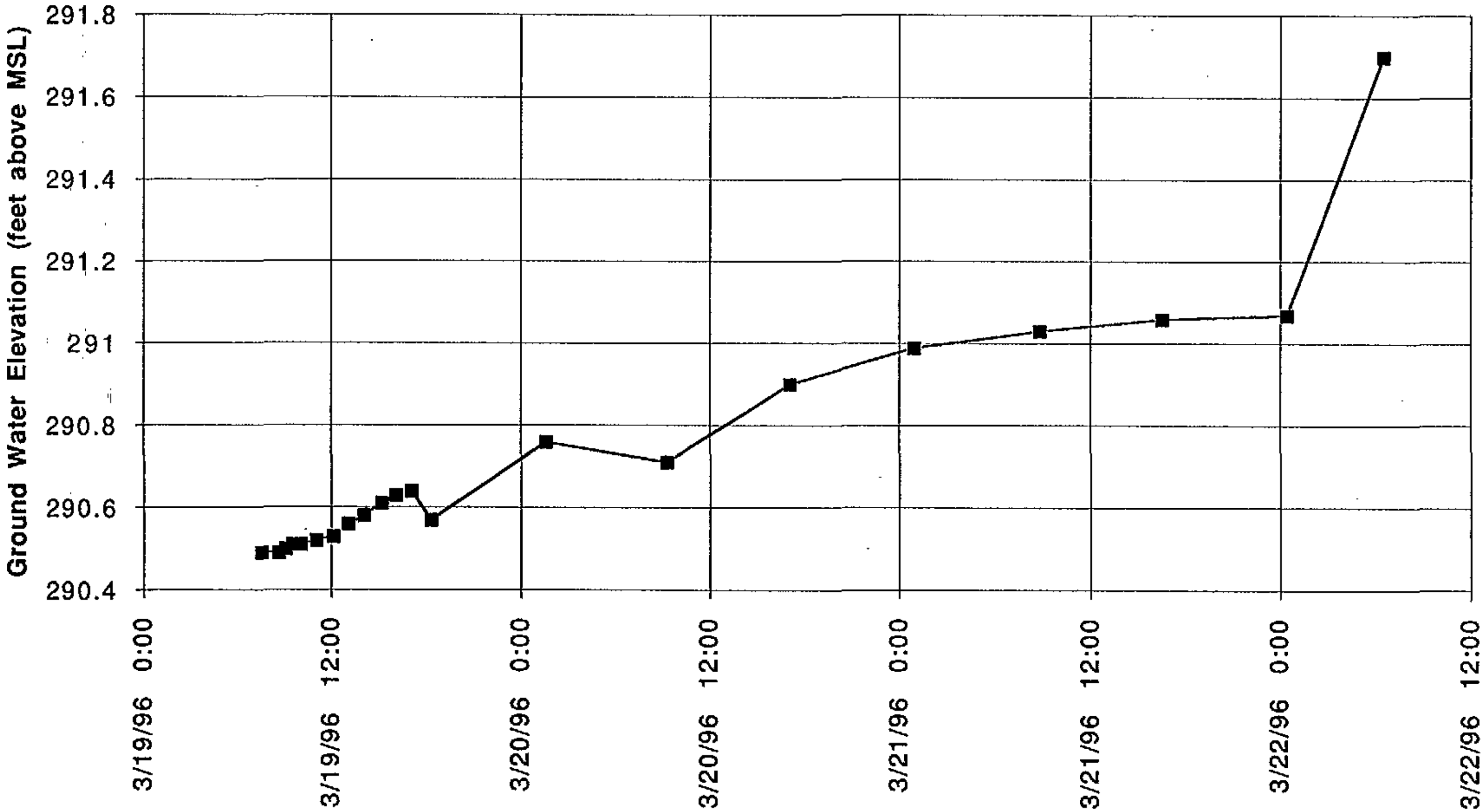


THE ERM GROUP

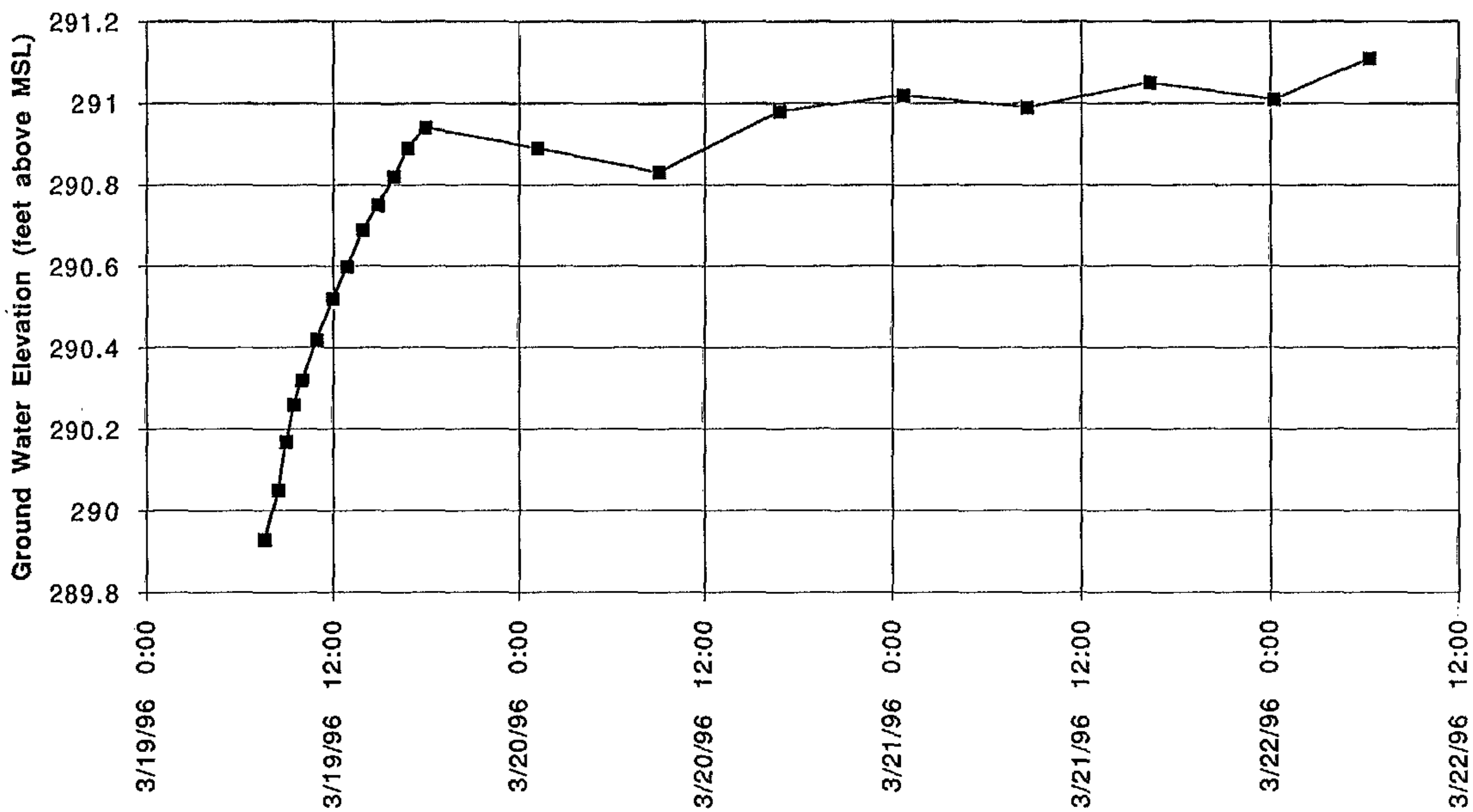
Recovery Test HIA-13
Barometric Pressure
Data Logger Measurements



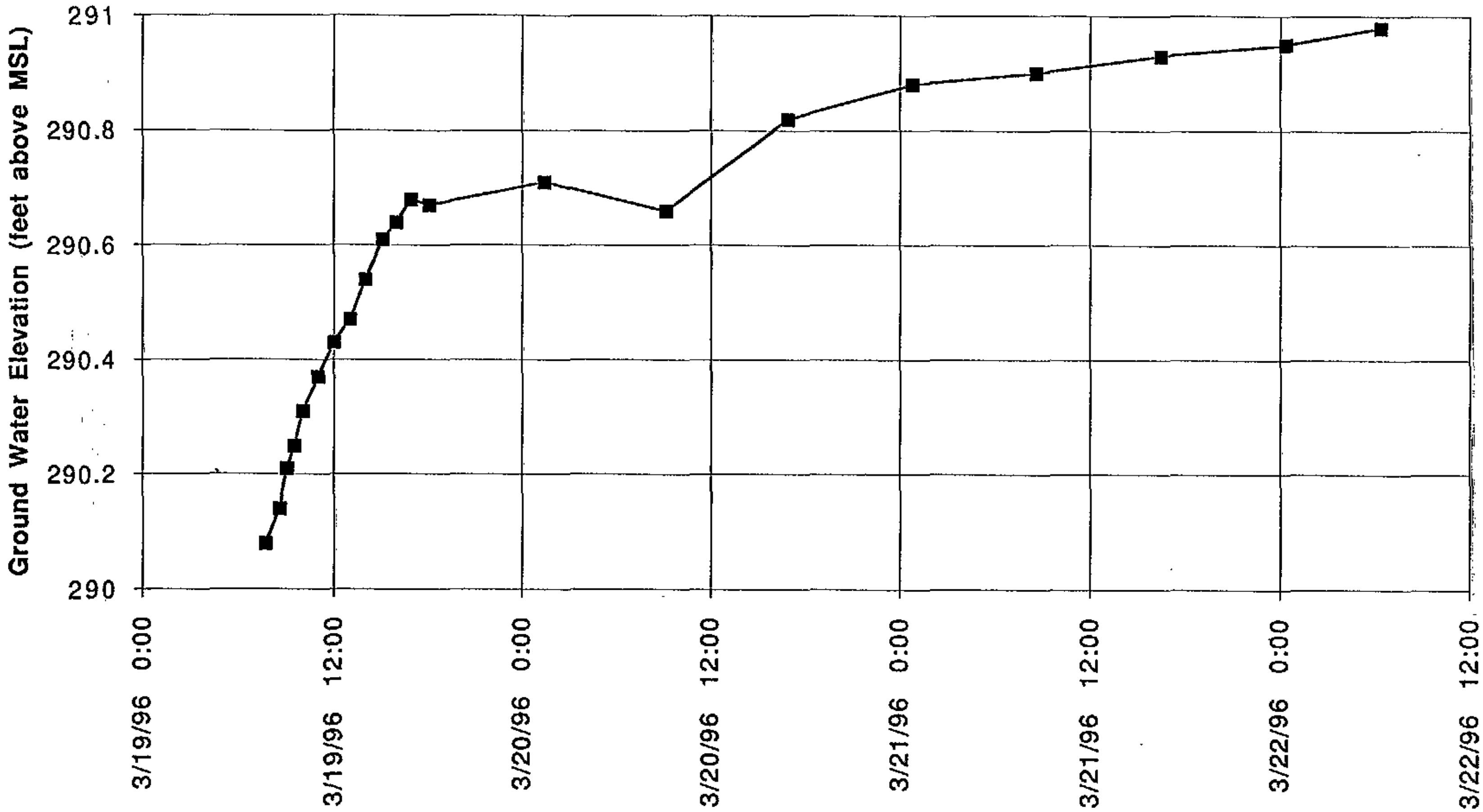
Recovery Test HIA-13
Observation Well ERM-3S
Hand Measurements



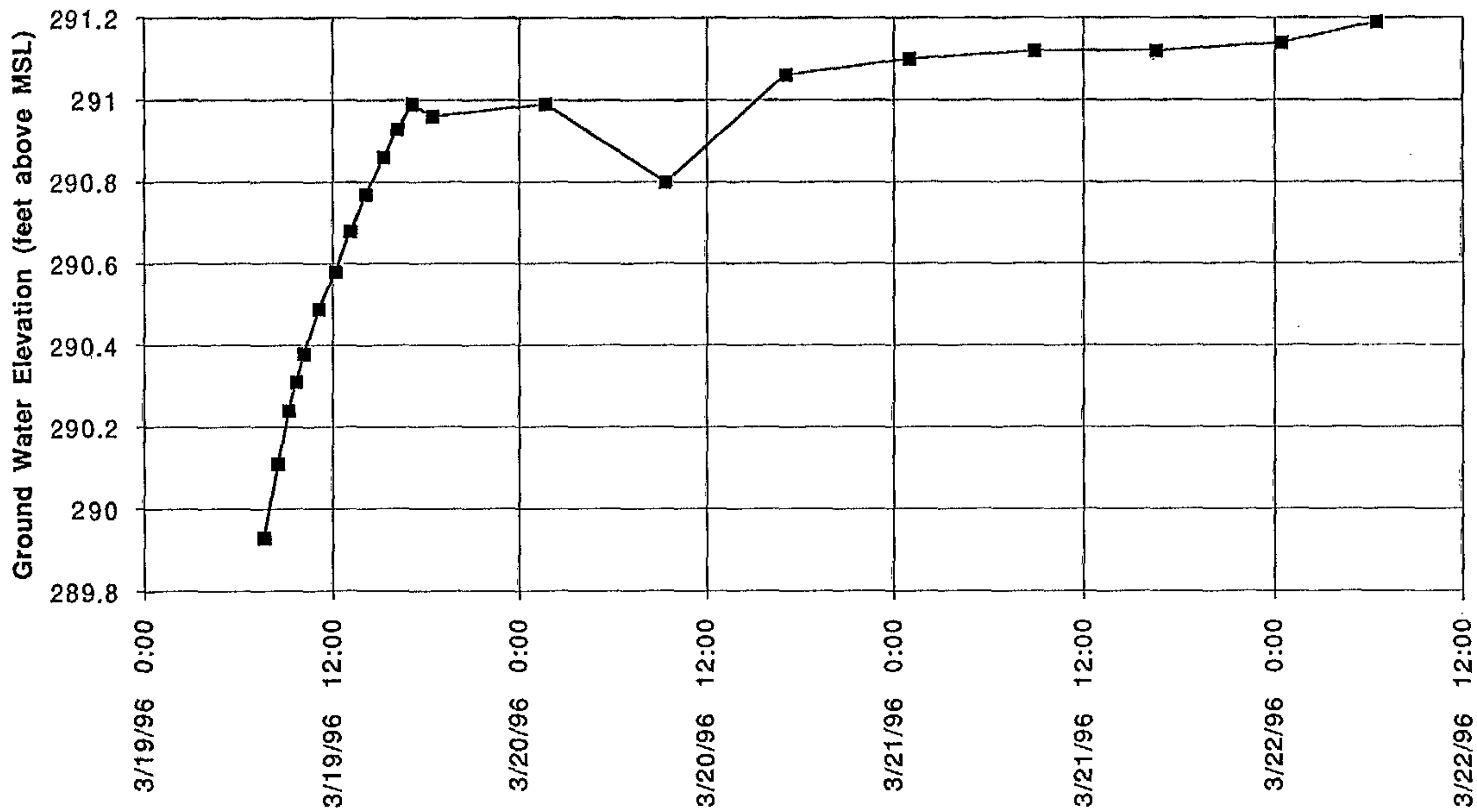
Recovery Test HIA-13
Observation Well ERM-4S
Hand Measurements



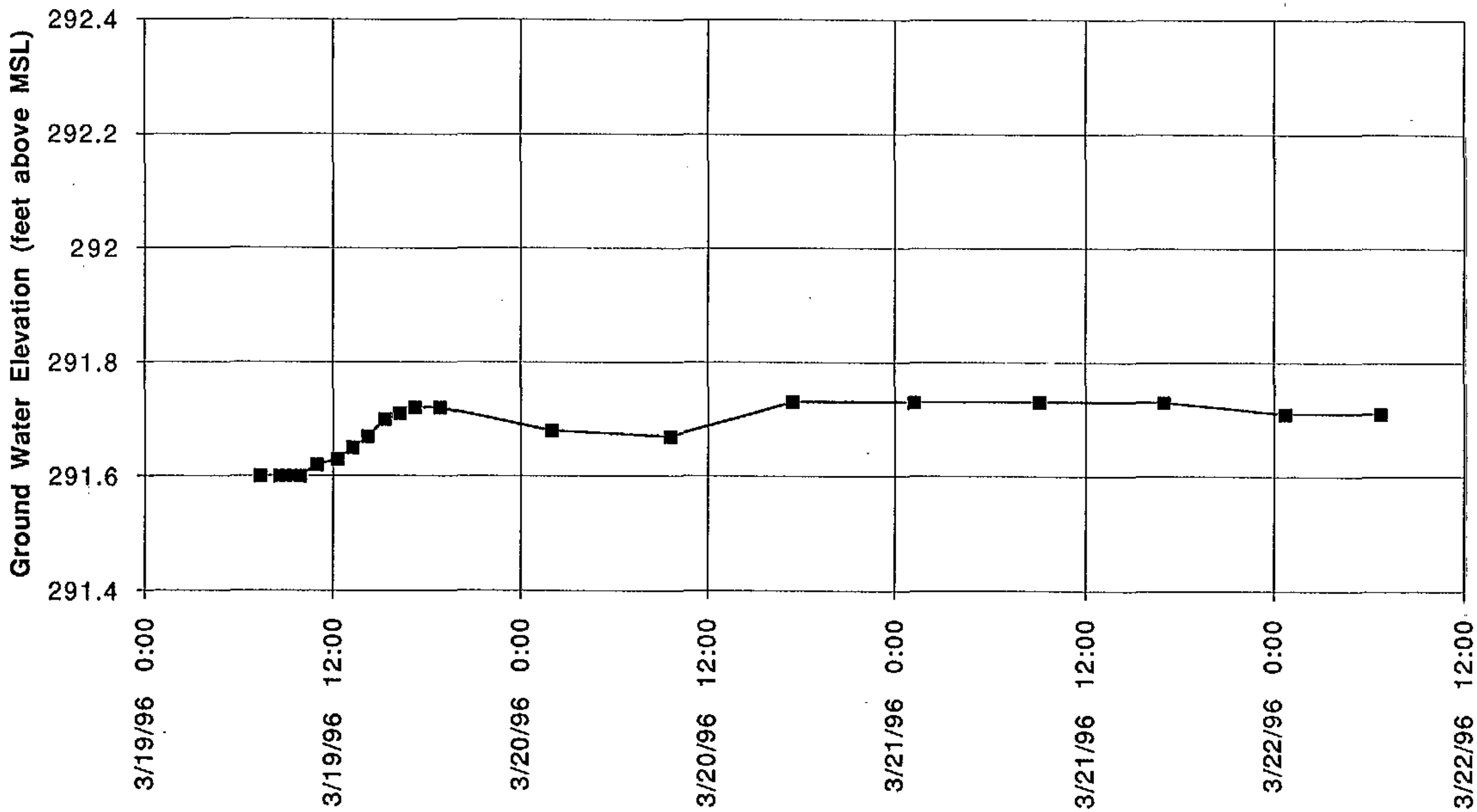
Recovery Test HIA-13
Observation Well ERM-5S
Hand Measurements



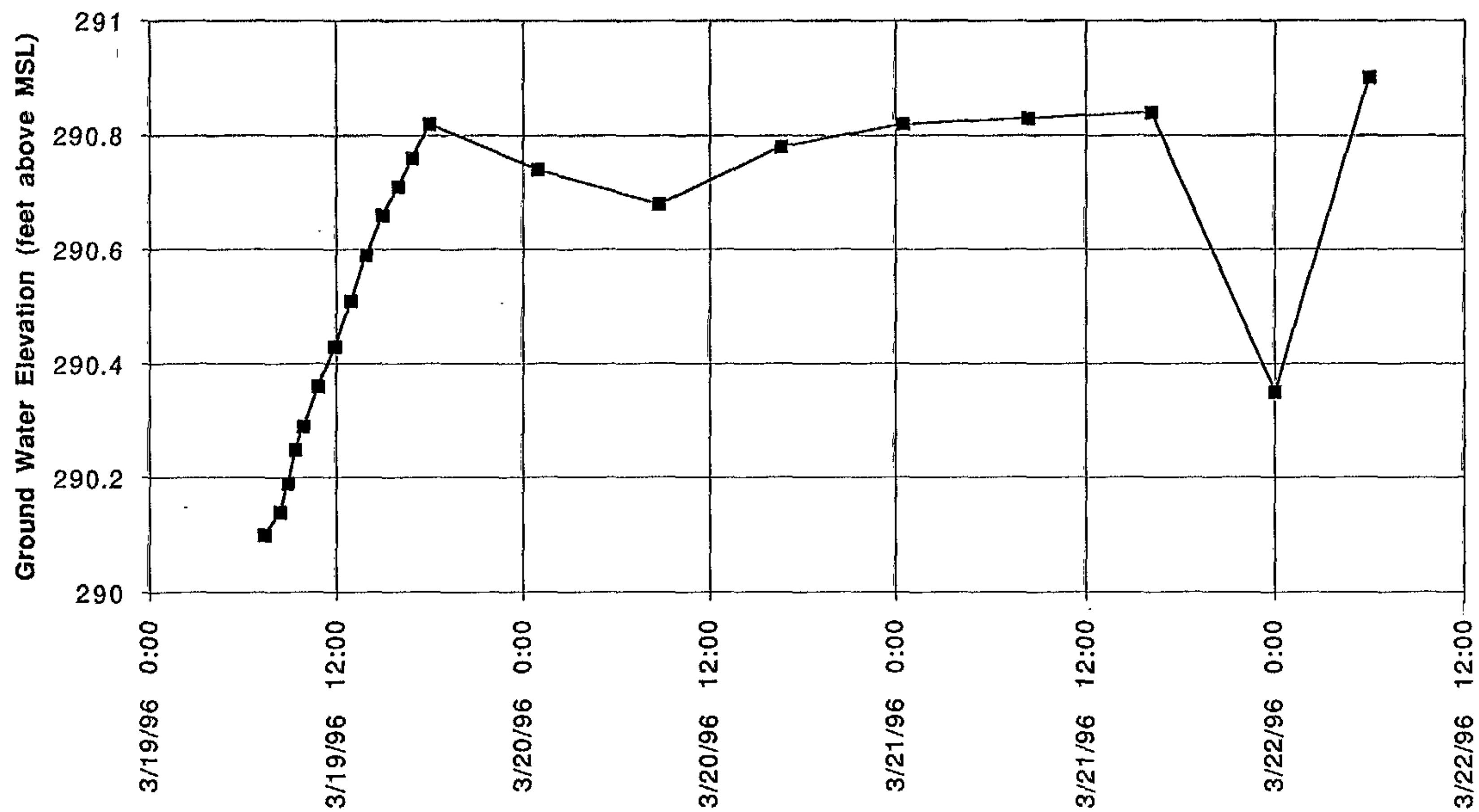
Recovery Test HIA-13
Observation Well ERM-6S
Hand Measurements



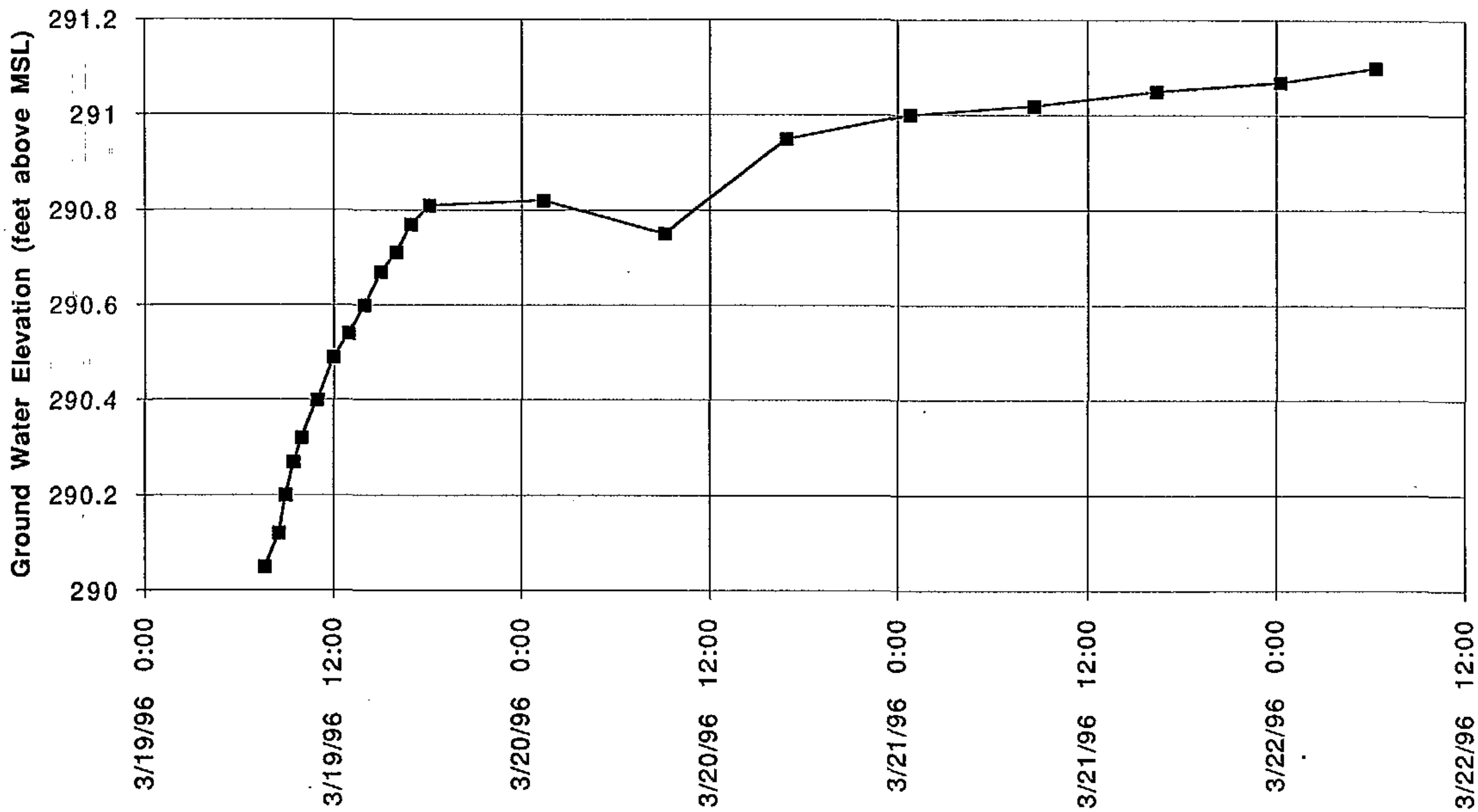
Recovery Test HIA-13
Observation Well ERM-10I
Hand Measurements



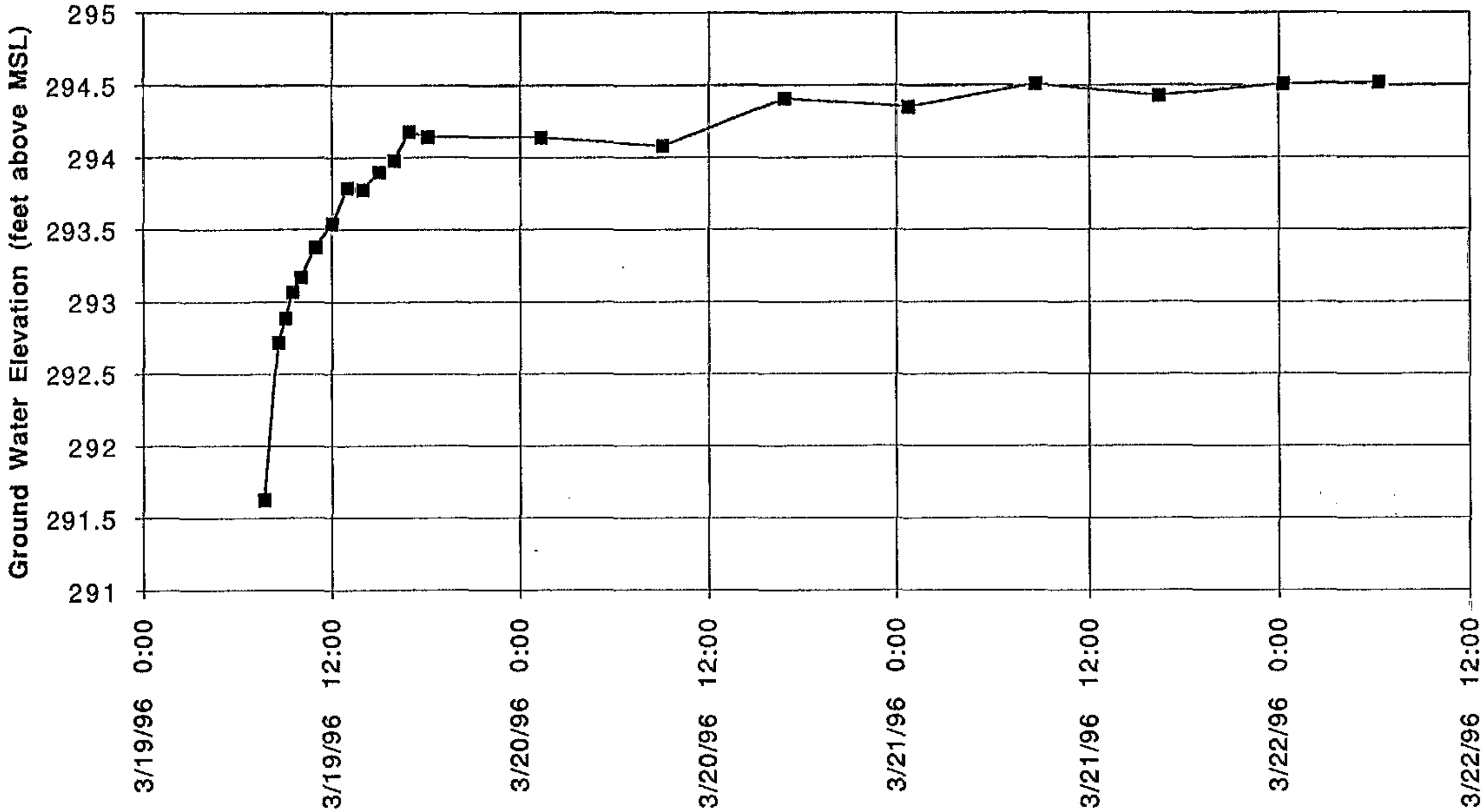
Recovery Test HIA-13
Observation Well ERM-27S
Hand Measurements



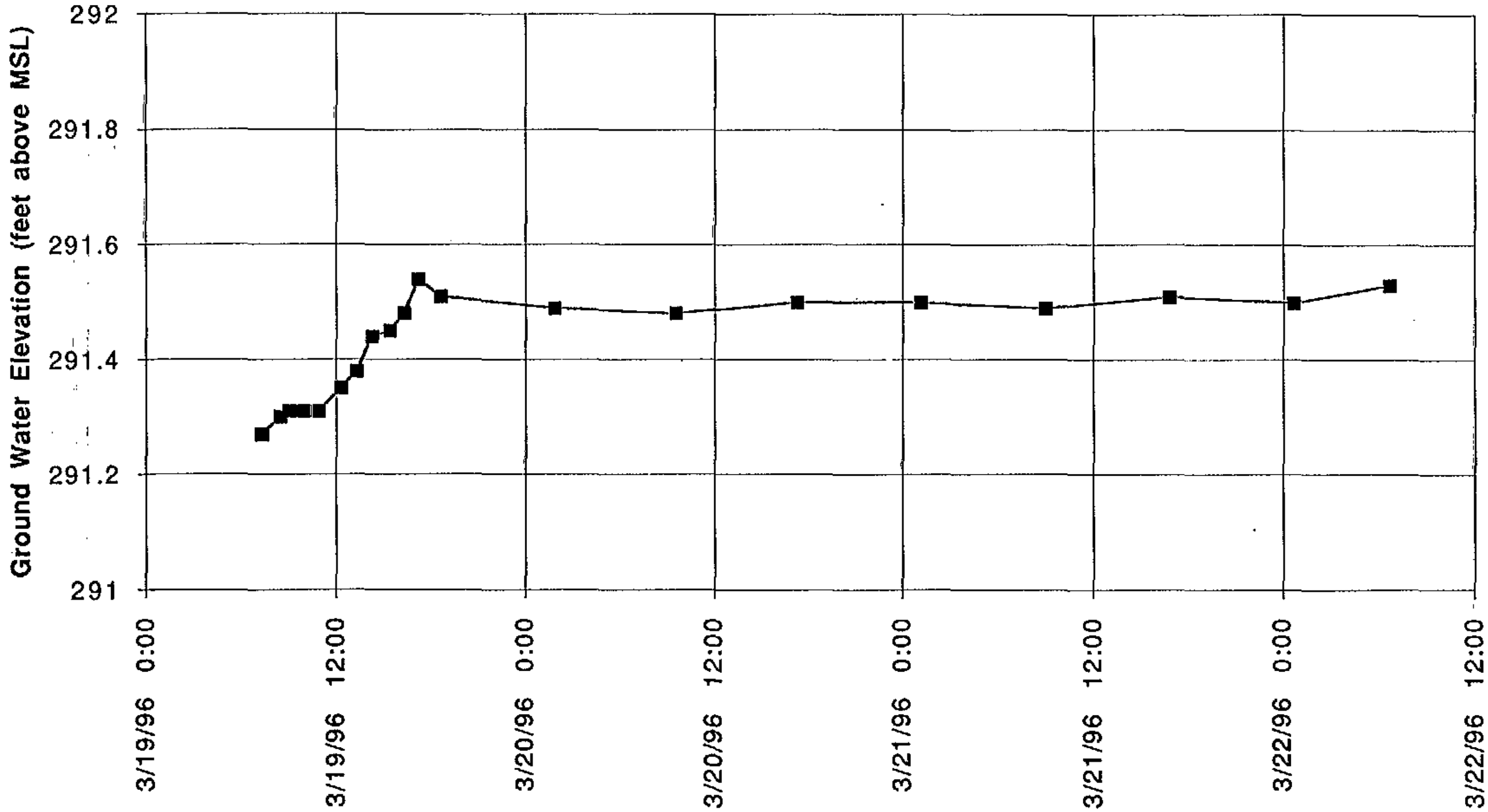
Recovery Test HIA-13
Observation Well GF-218
Hand Measurements



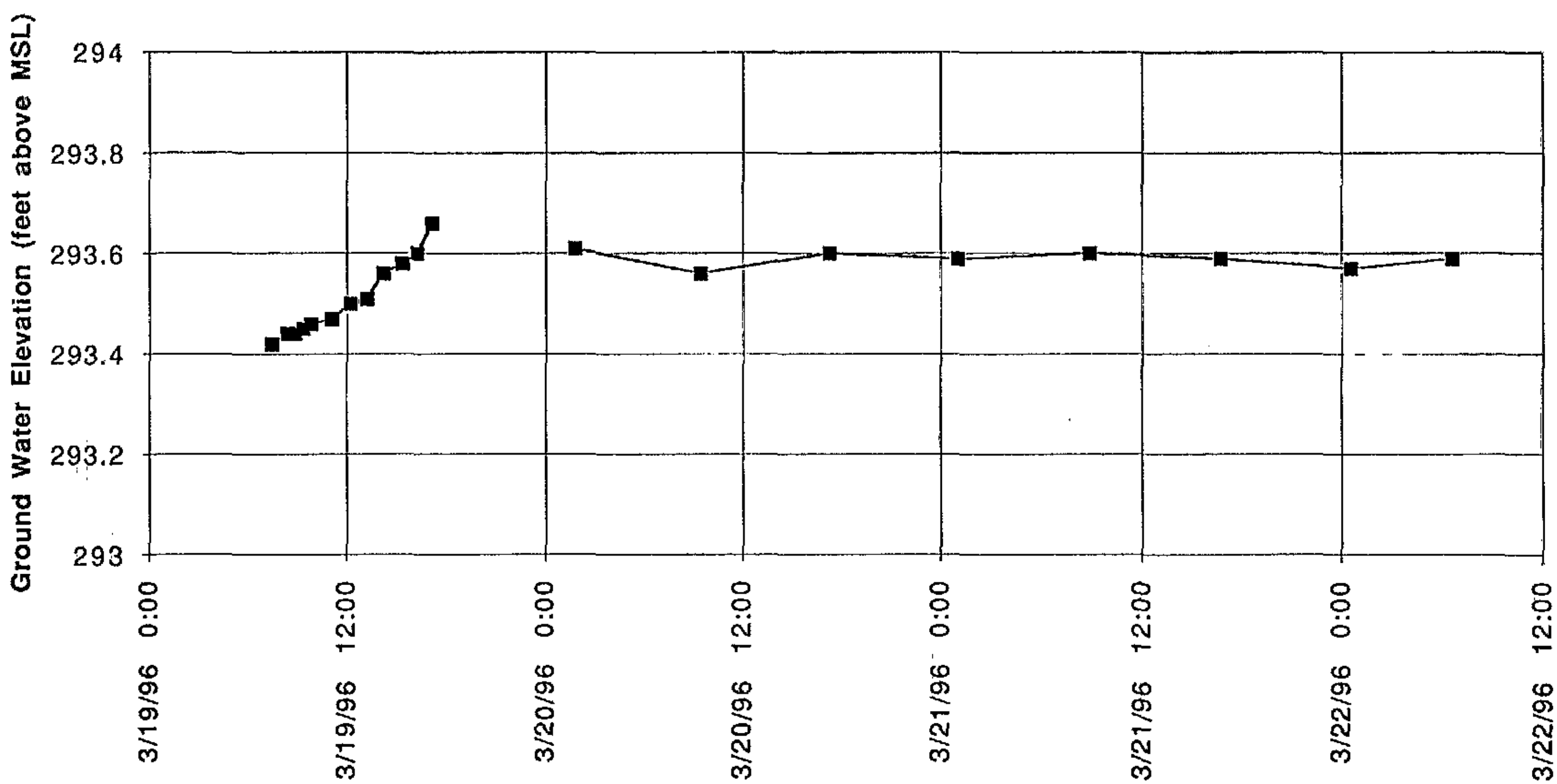
Recovery Test HIA-13
Observation Well GF-318
Hand Measurements



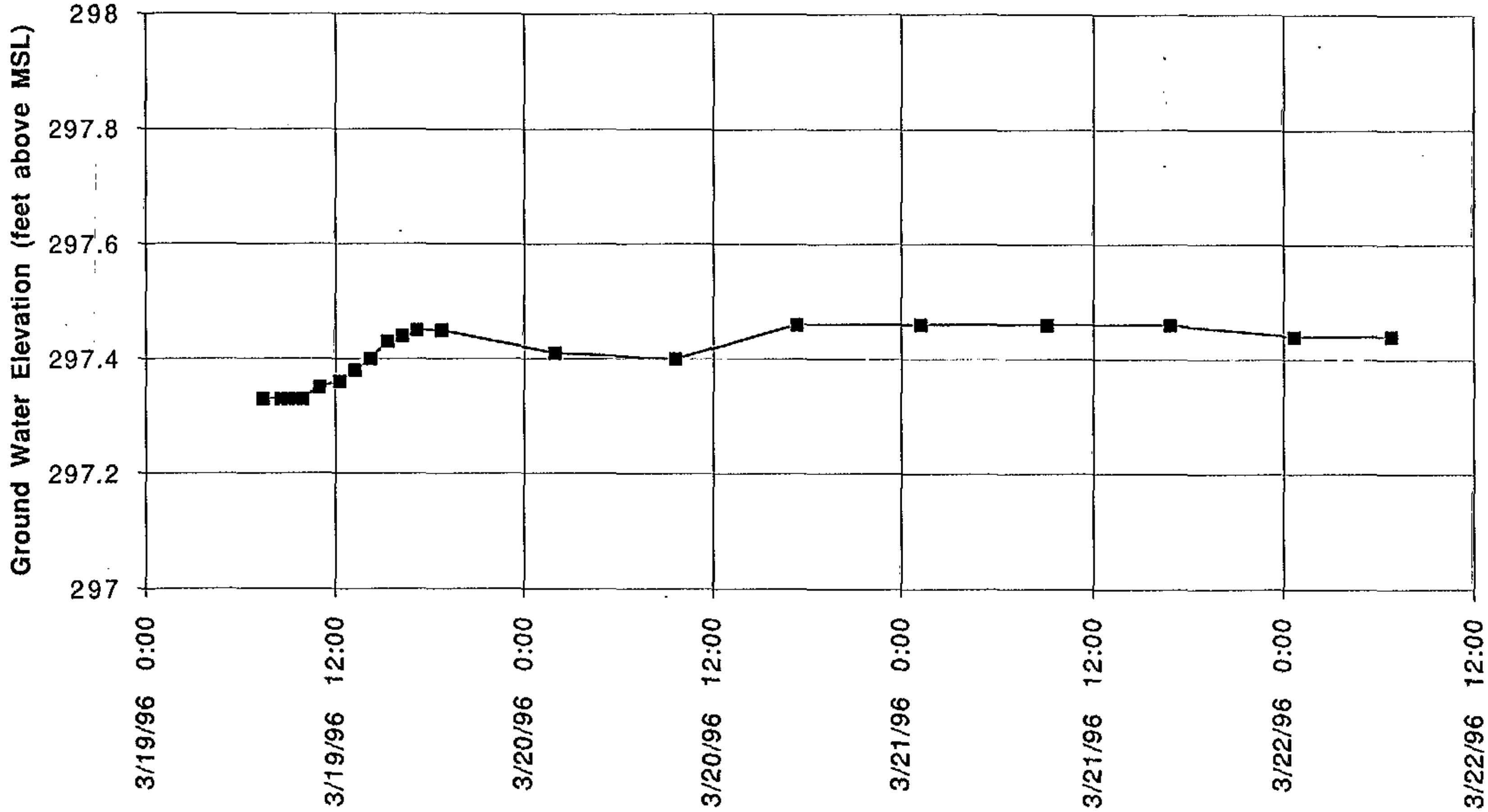
Recovery Test HIA-13
Observation Well GF-219
Hand Measurements



Recovery Test HIA-13
Observation Well GF-220
Hand Measurements

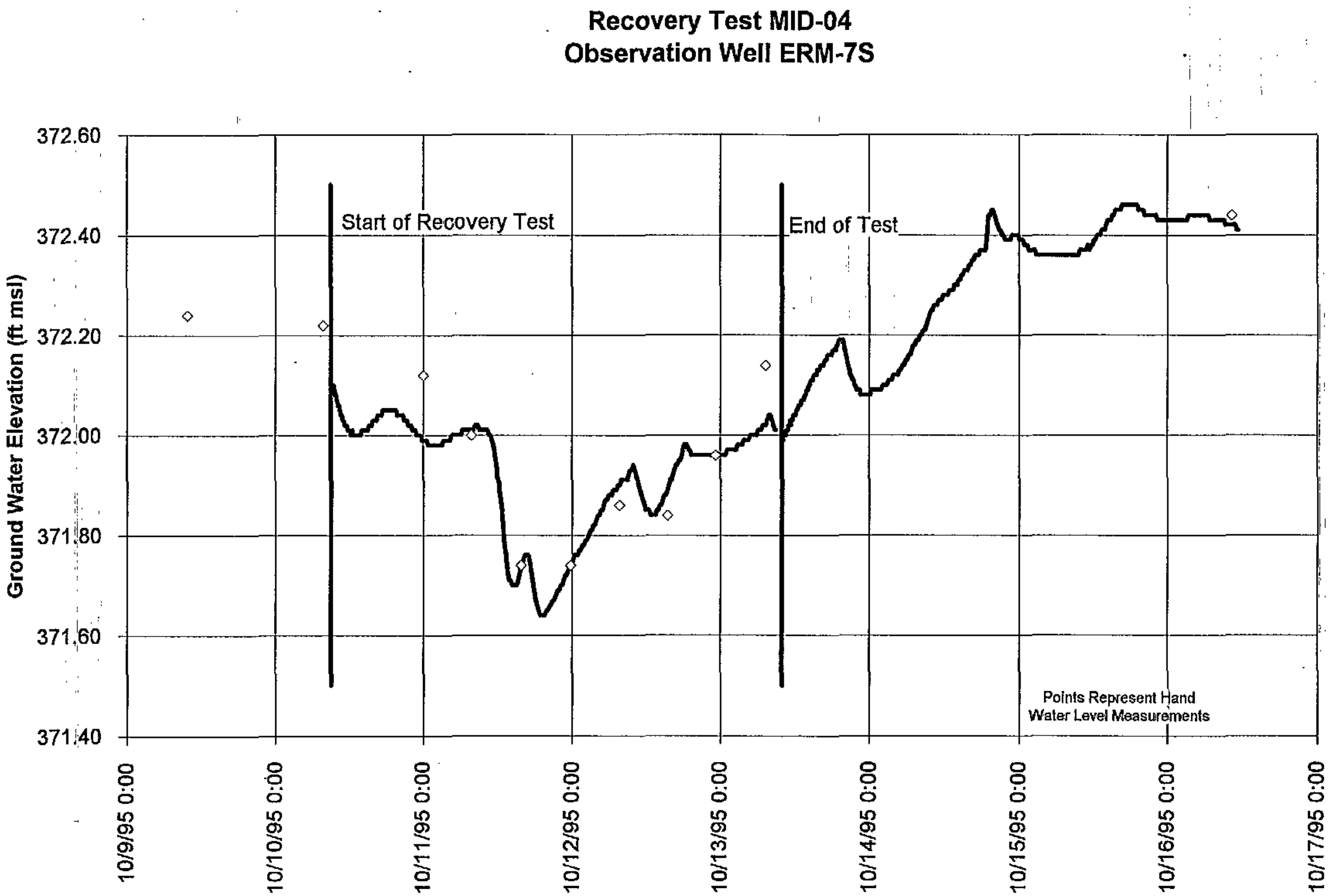


Recovery Test HIA-13
Observation Well RFW-4
Hand Measurements

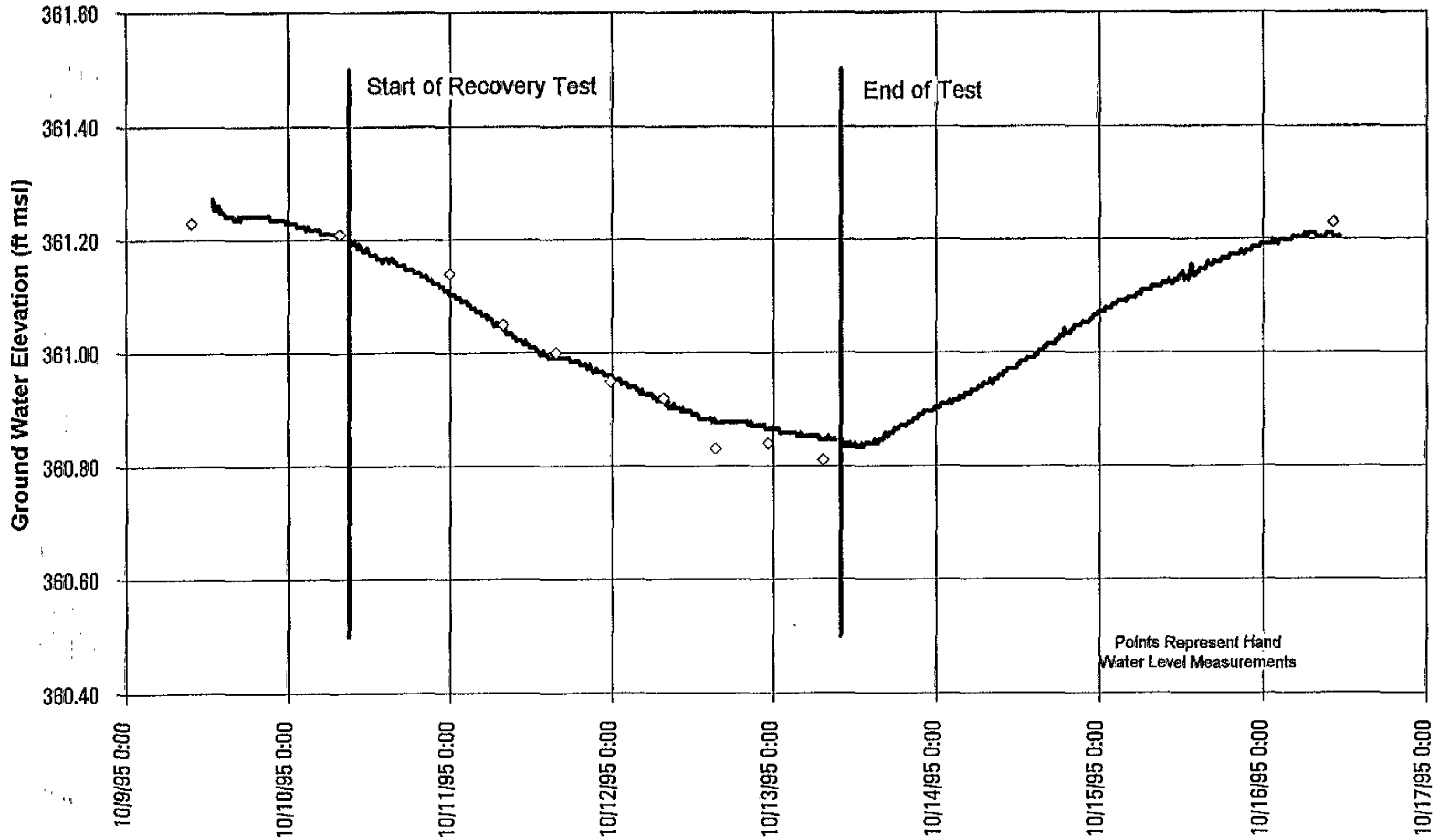


Hydrographs-Recovery Test MID-04

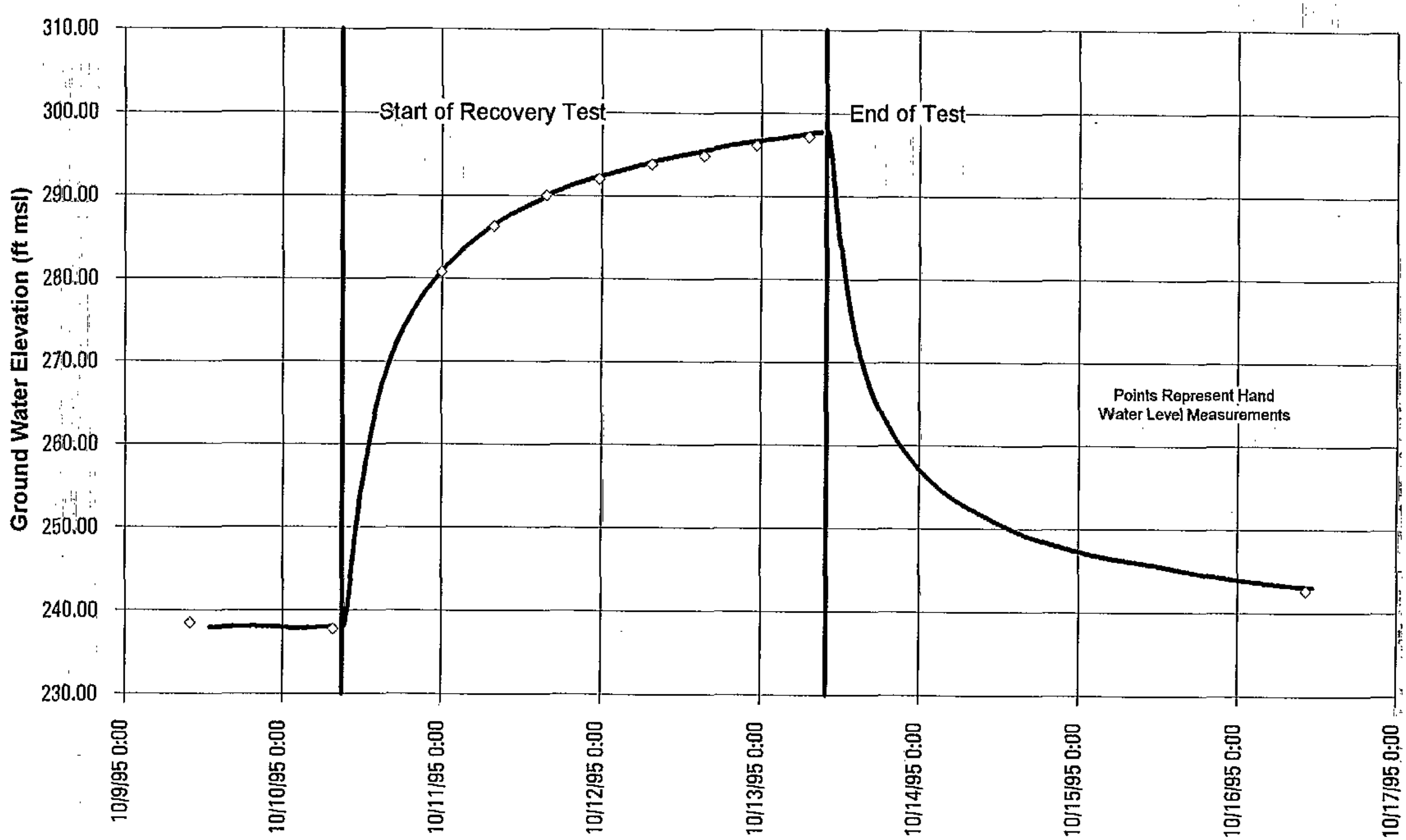
Filename: [MID4-7S.XLC]
Date Printed:11/20/95



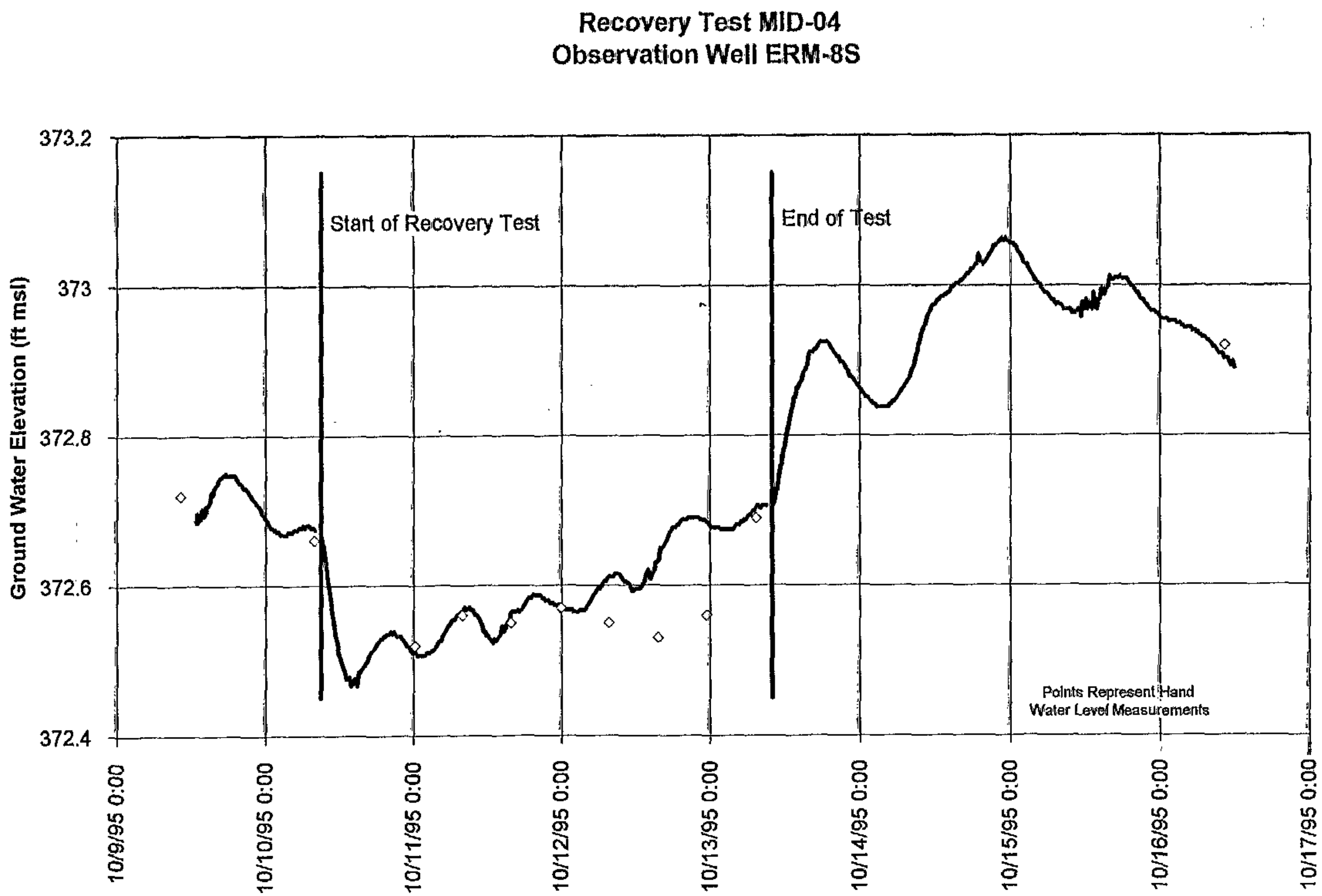
Recovery Test MID-04
Observation Wells ERM-7I



Recovery Test MID-04
Observation Wells ERM-7D

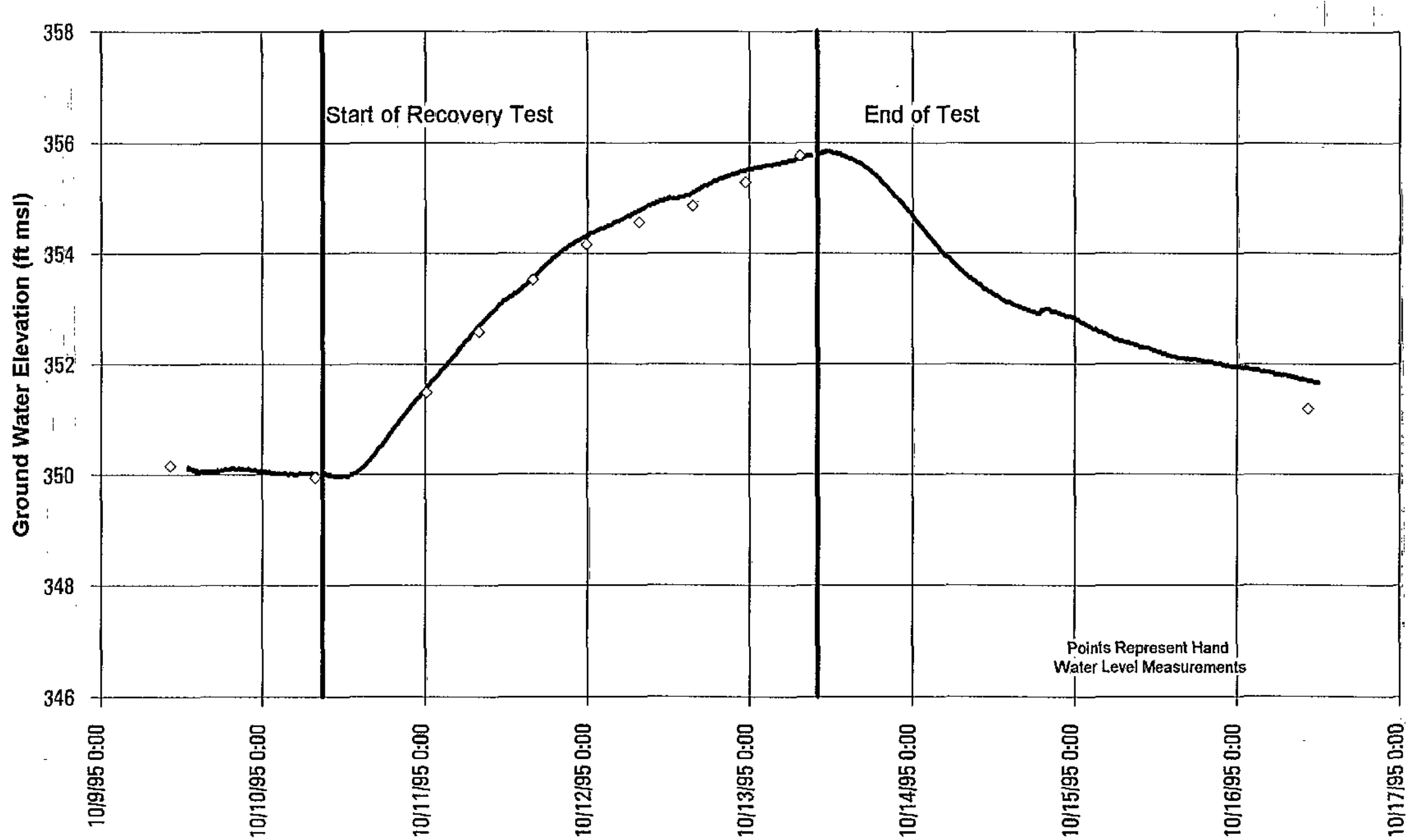


Filename {MID4-$SB XLW}BS XLC
Date Printed: 11/20/95



Filename: [REV-8ID [illegible]]8ID.XLC
Date Printed: 11/20/95

Recovery Test MID-04
Observation Wells ERM-8I



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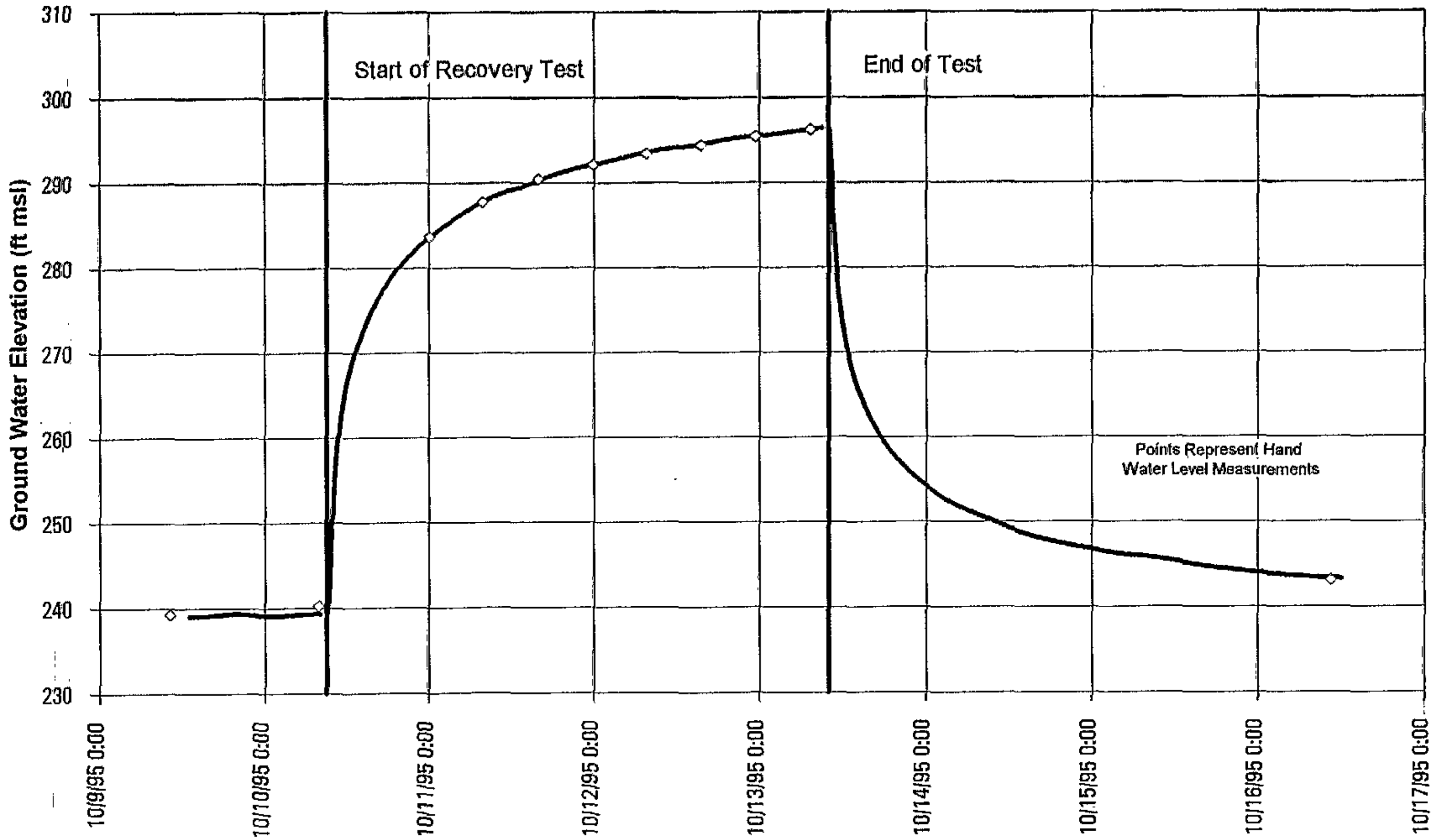
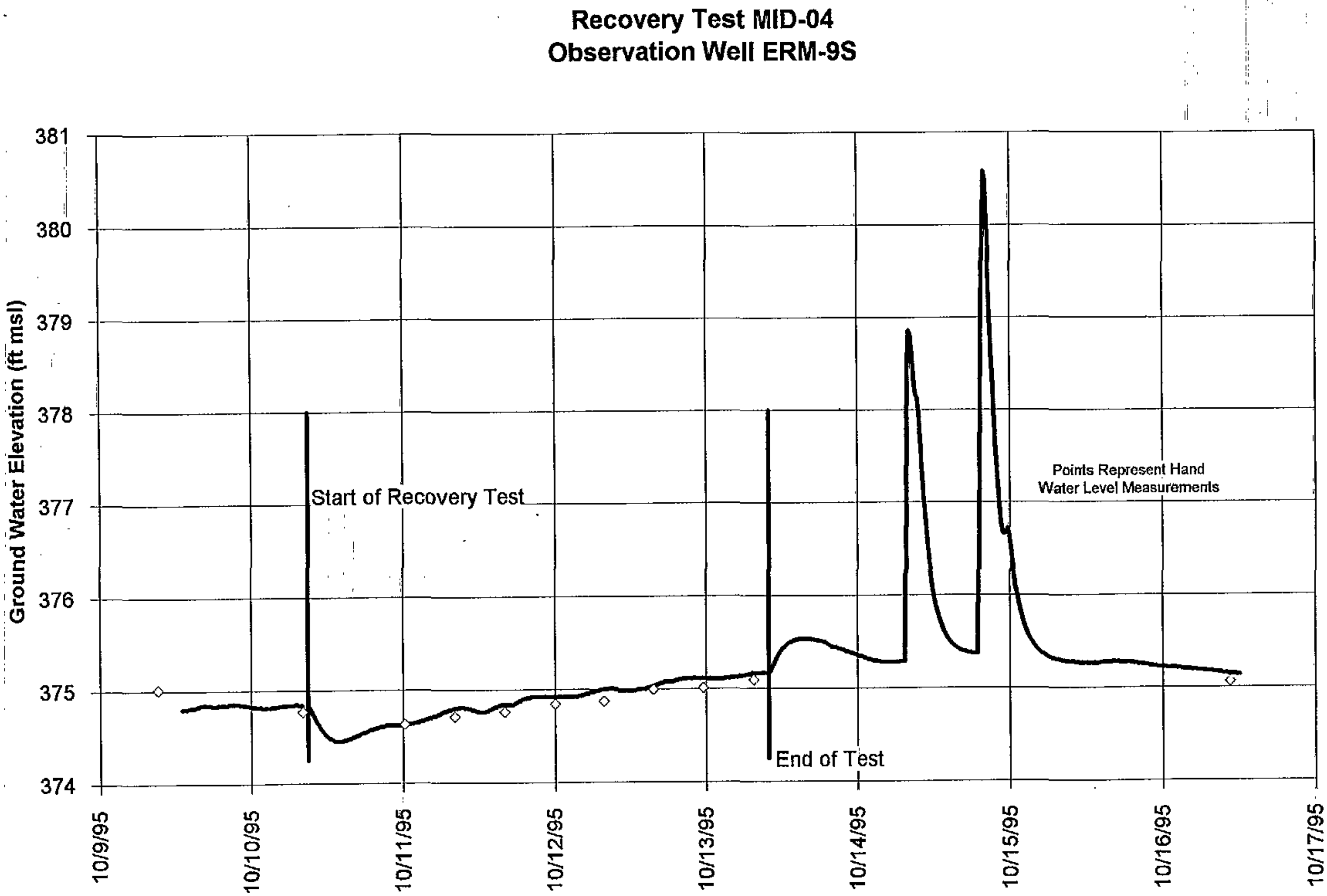
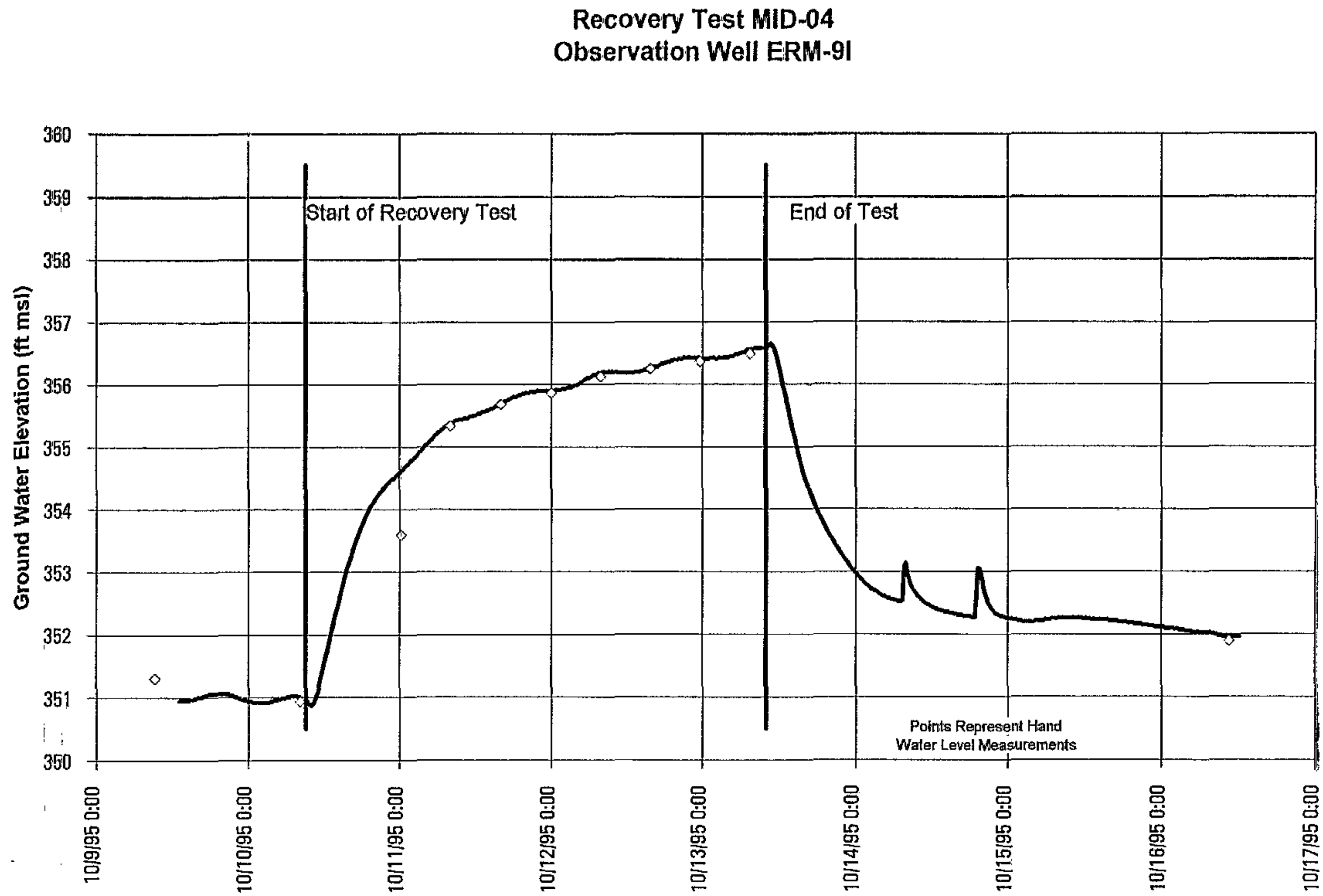
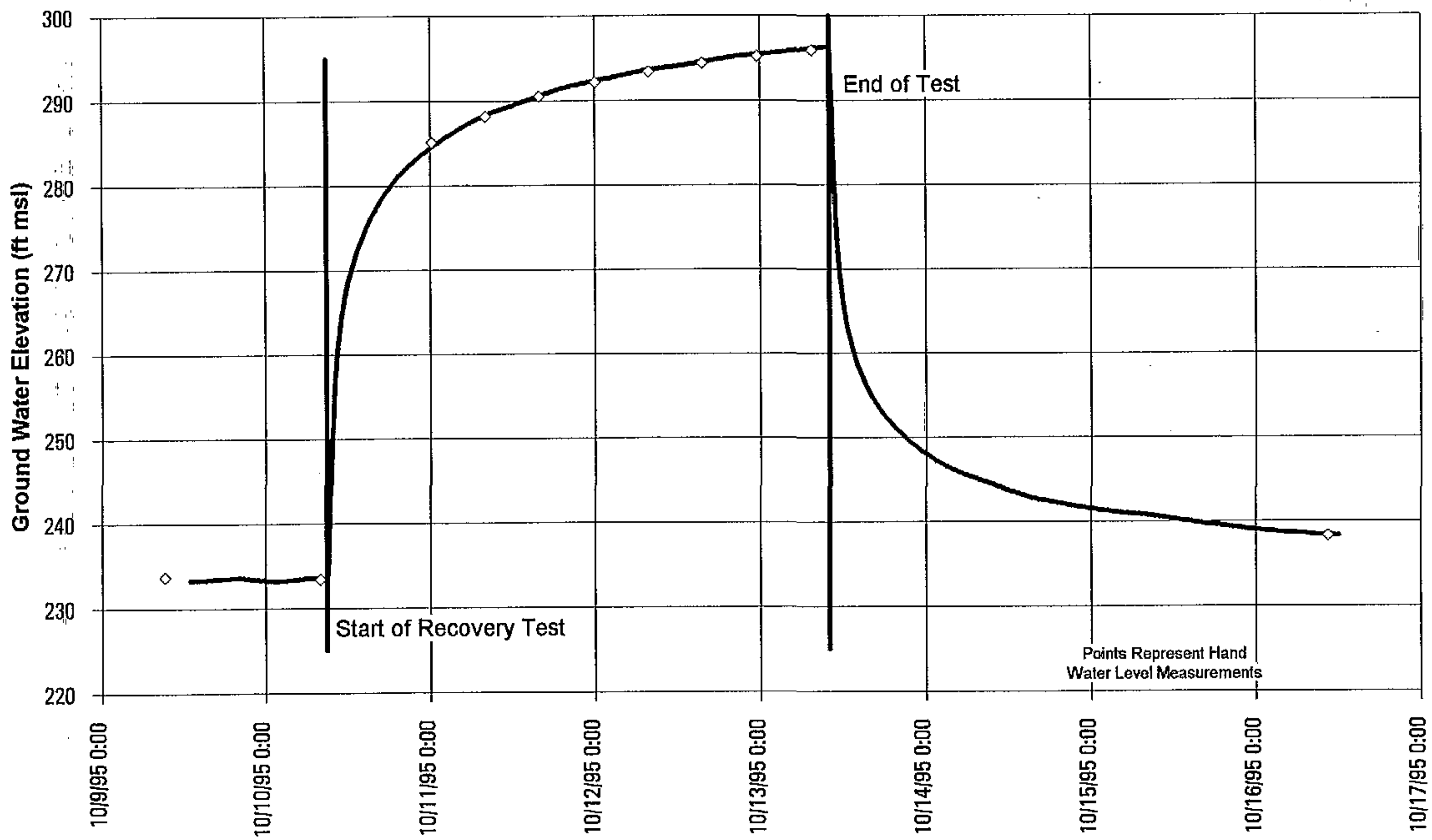
Recovery Test MID-04
Observation Wells ERM-8D




Recovery Test MID-04
Observation Well ERM-9S
Ground Water Elevation (ft msl)
381
380
379
378
377
376
375
374
10/9/95
10/10/95
10/11/95
10/12/95
10/13/95
10/14/95
10/15/95
10/16/95
10/17/95
Start of Recovery Test
End of Test
Points Represent Hand
Water Level Measurements

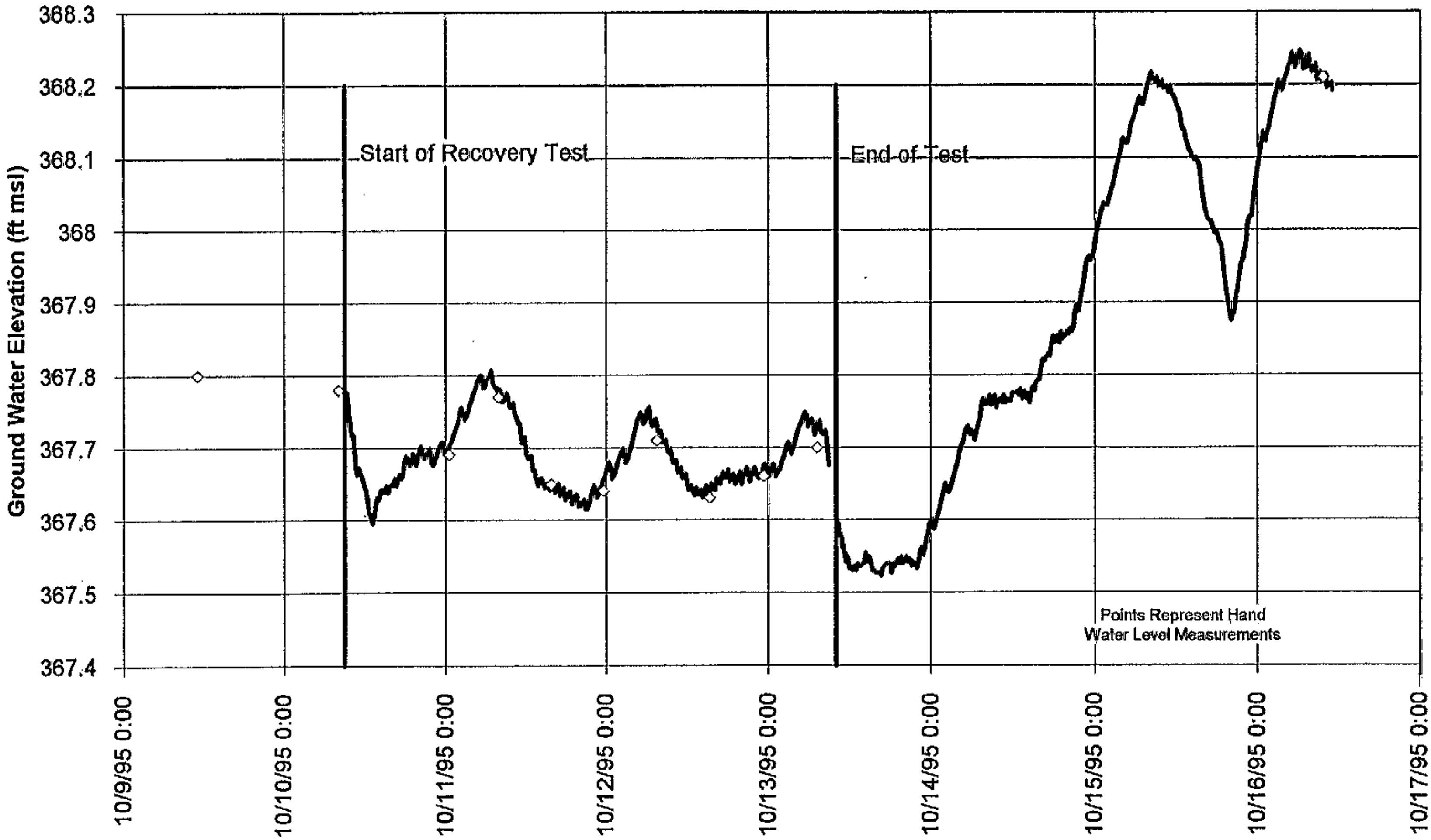

Recovery Test MID-04
Observation Well ERM-9I
Ground Water Elevation (ft msl)
360
359
358
357
356
355
354
353
352
351
350
Start of Recovery Test
End of Test
Points Represent Hand
Water Level Measurements
10/9/95 0:00
10/10/95 0:00
10/11/95 0:00
10/12/95 0:00
10/13/95 0:00
10/14/95 0:00
10/15/95 0:00
10/16/95 0:00
10/17/95 0:00

Recovery Test MID-04
Observation Well ERM-9D

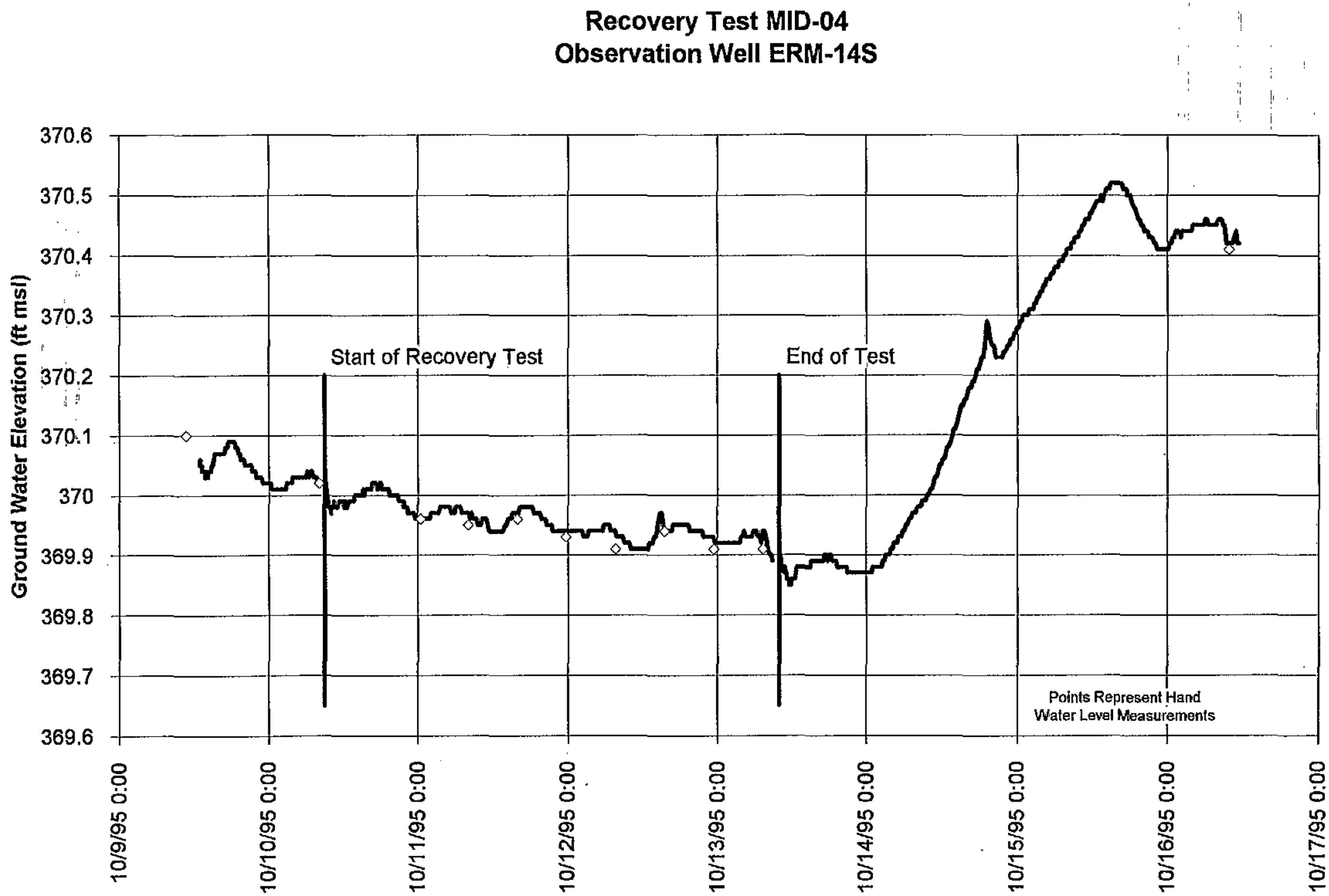


Filename [MID413IS XLW]13I XLC
Date Printed 11/20/95

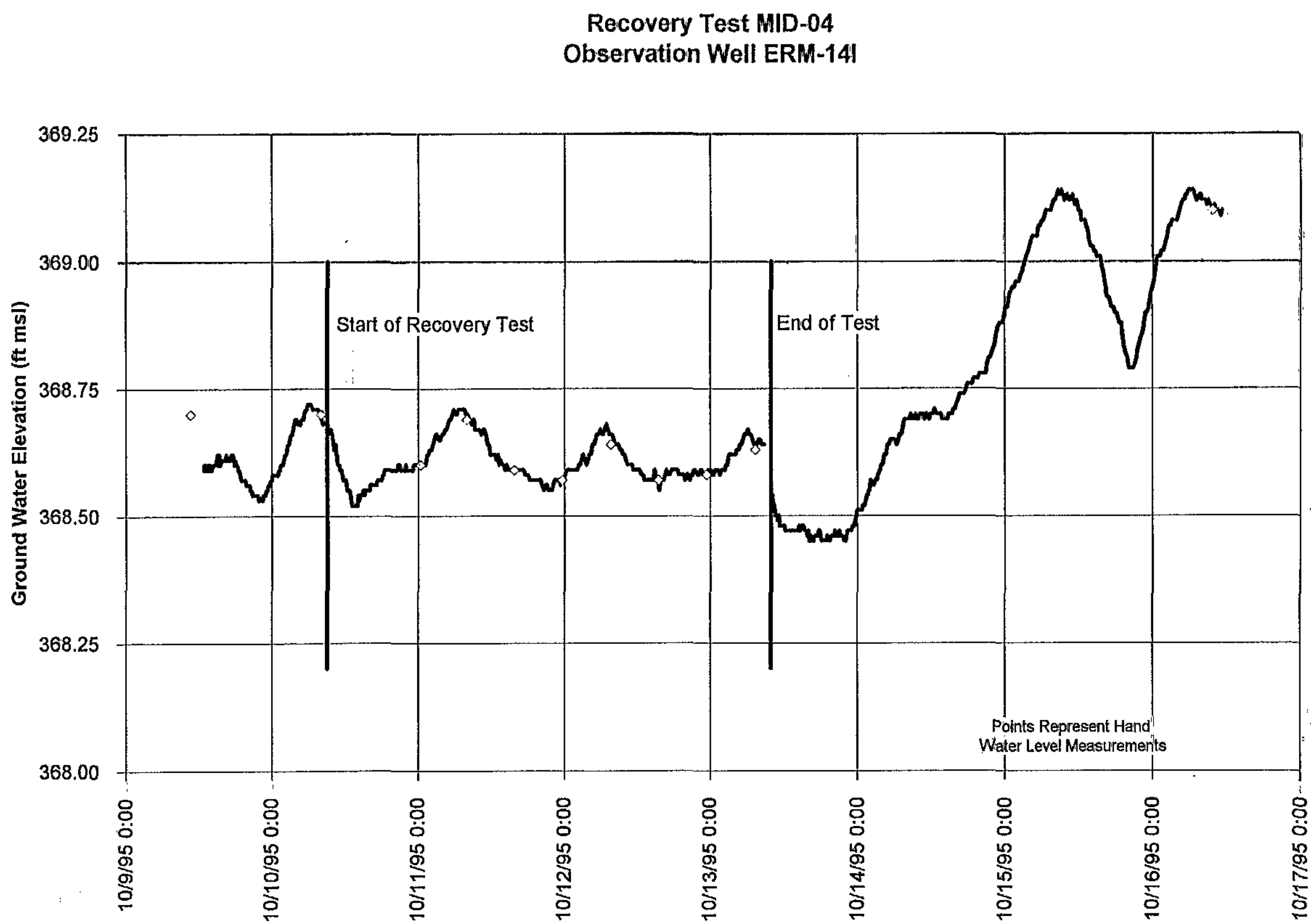
Recovery Test MID-04
Observation Well ERM-13I



THE ERM GROUP


Recovery Test MID-04
Observation Well ERM-14S
Ground Water Elevation (ft msl)
370.6
370.5
370.4
370.3
370.2
370.1
370
369.9
369.8
369.7
369.6
Start of Recovery Test
End of Test
Points Represent Hand
Water Level Measurements
10/9/95 0:00
10/10/95 0:00
10/11/95 0:00
10/12/95 0:00
10/13/95 0:00
10/14/95 0:00
10/15/95 0:00
10/16/95 0:00
10/17/95 0:00

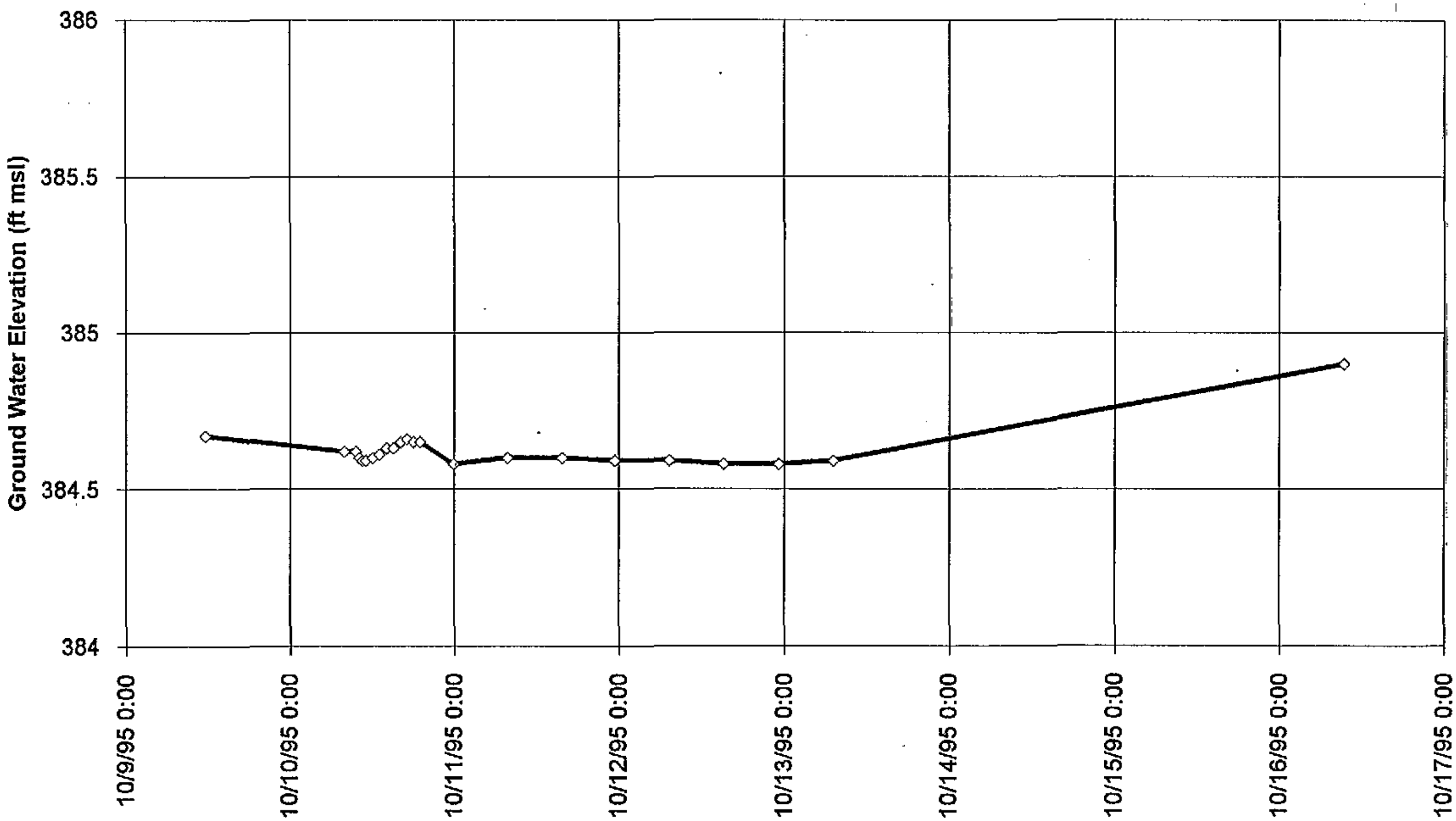
Filename [MID4-14I XLW]A-4-14I XLC
Date Printed 11/20/95



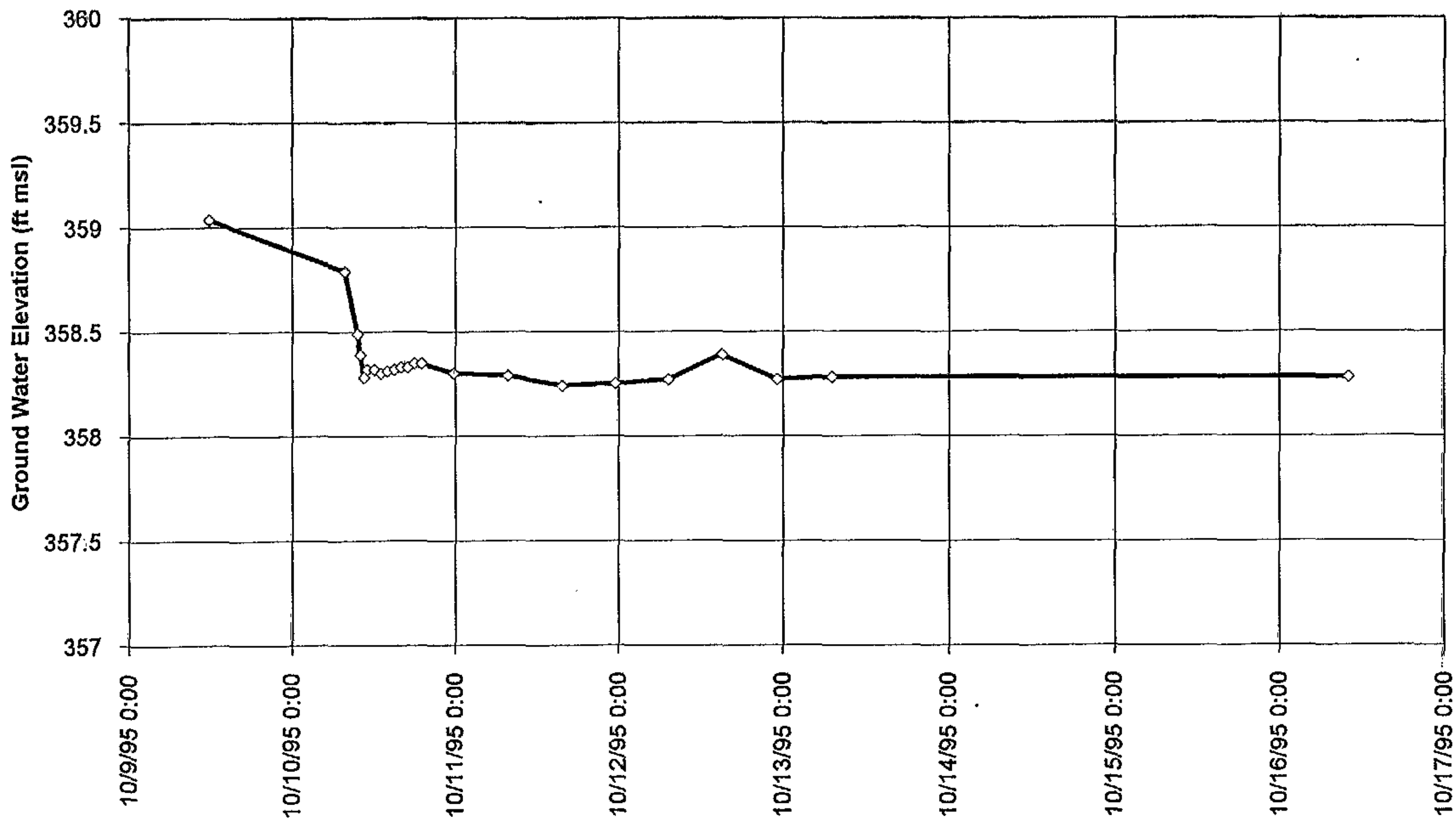
THE ERM GROUP

Filename:[MID4HAN W]15I.XLC
Date Printed: 11/7/95

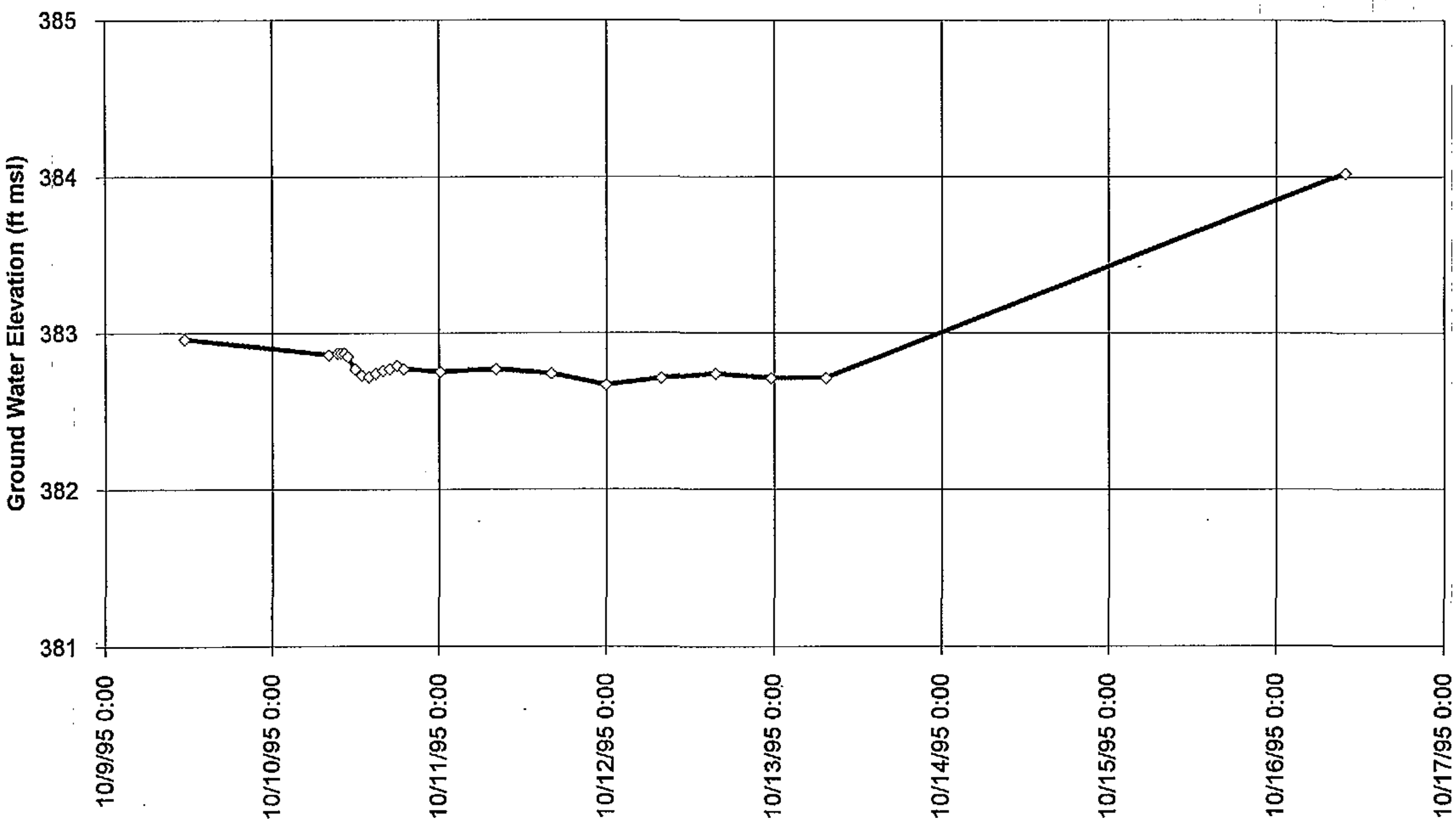
Recovery Test MID-04
Observation Well ERM-15I
Hand Water Level Measurements



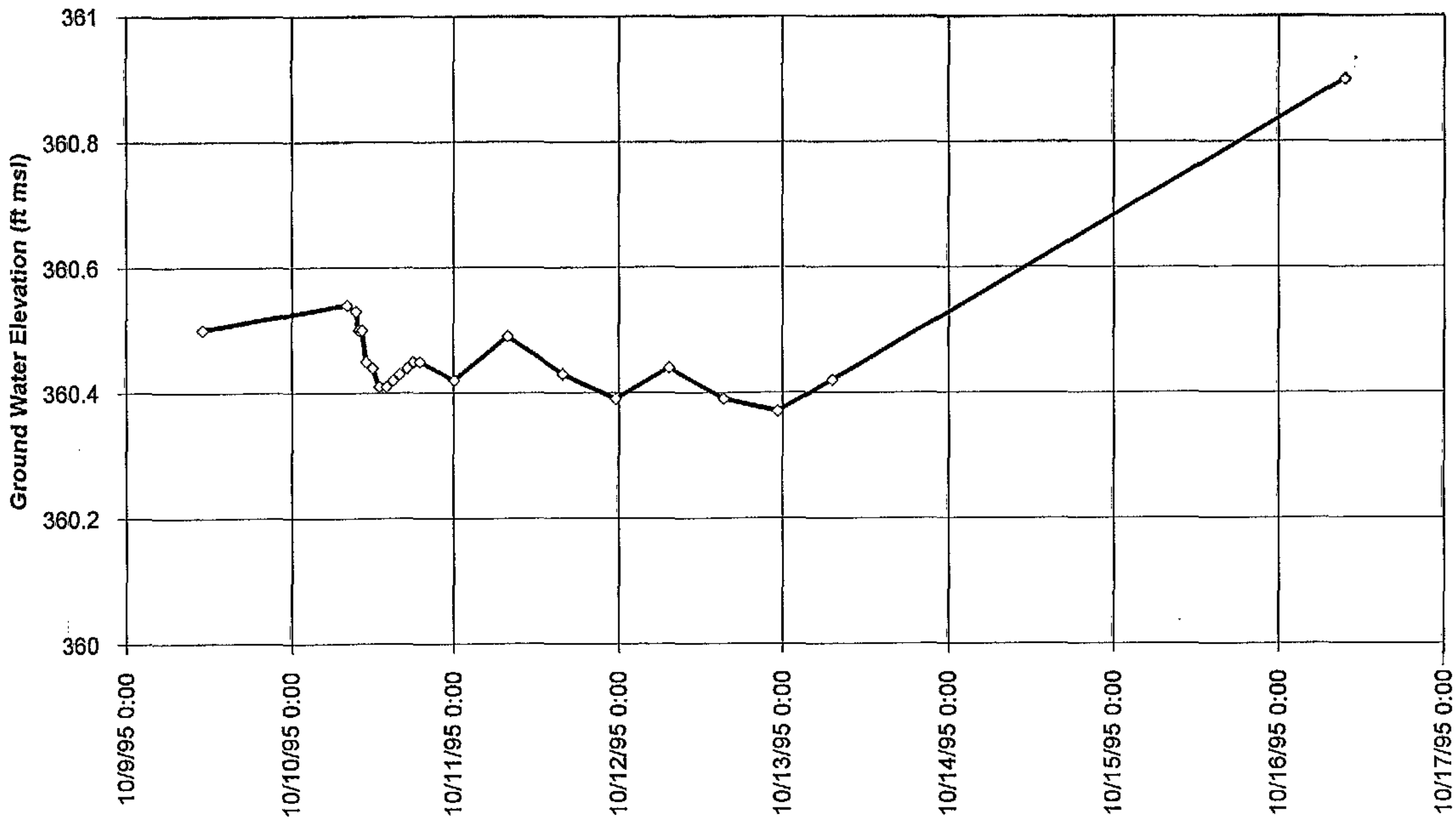
Recovery Test MID-04
Observation Well ERM-31I
Hand Water Level Measurements



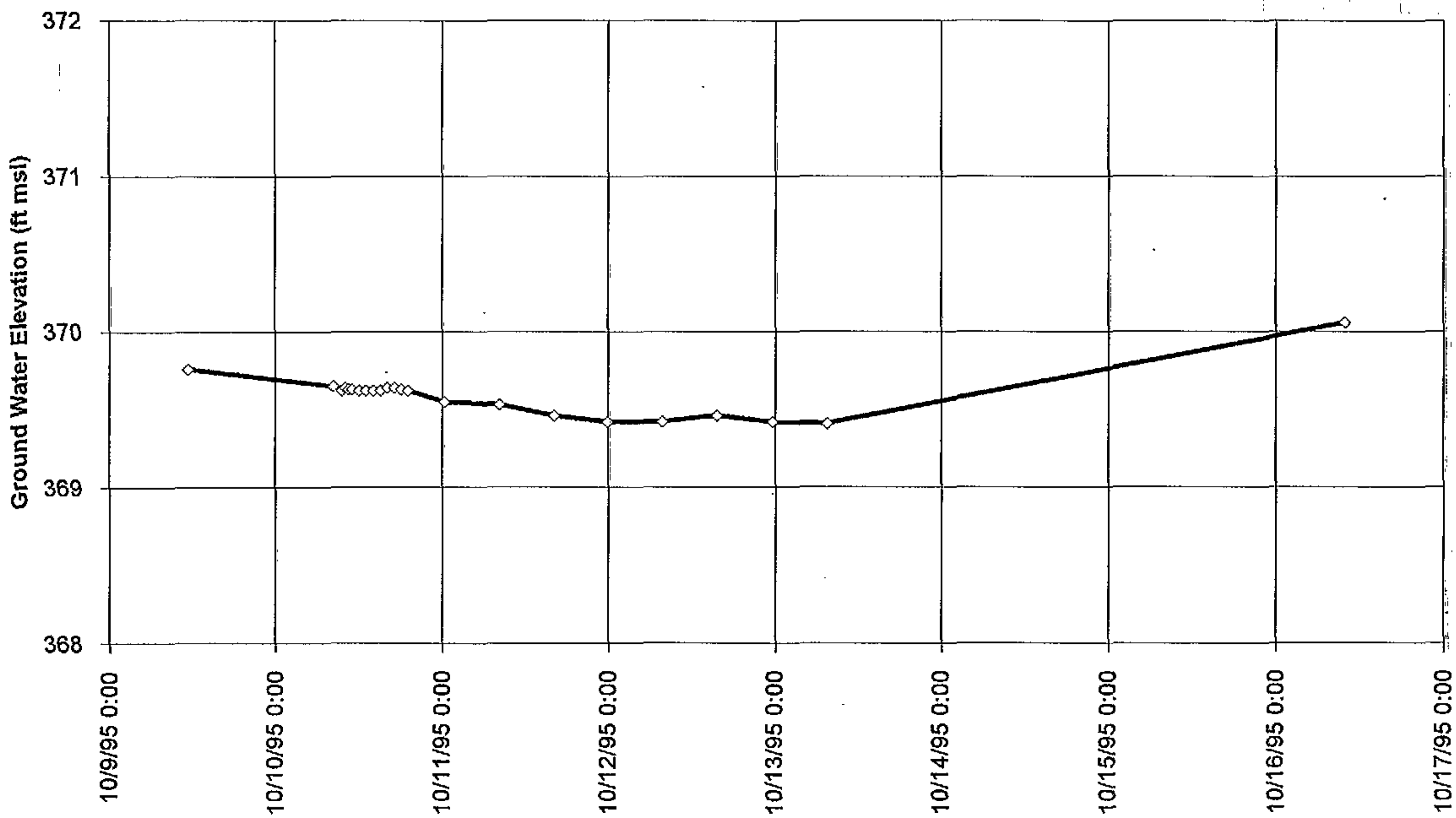
Recovery Test MID-04
Observation Well GF-301
Hand Water Level Measurements



Recovery Test MID-04
Observation Well GF-302
Hand Water Level Measurements



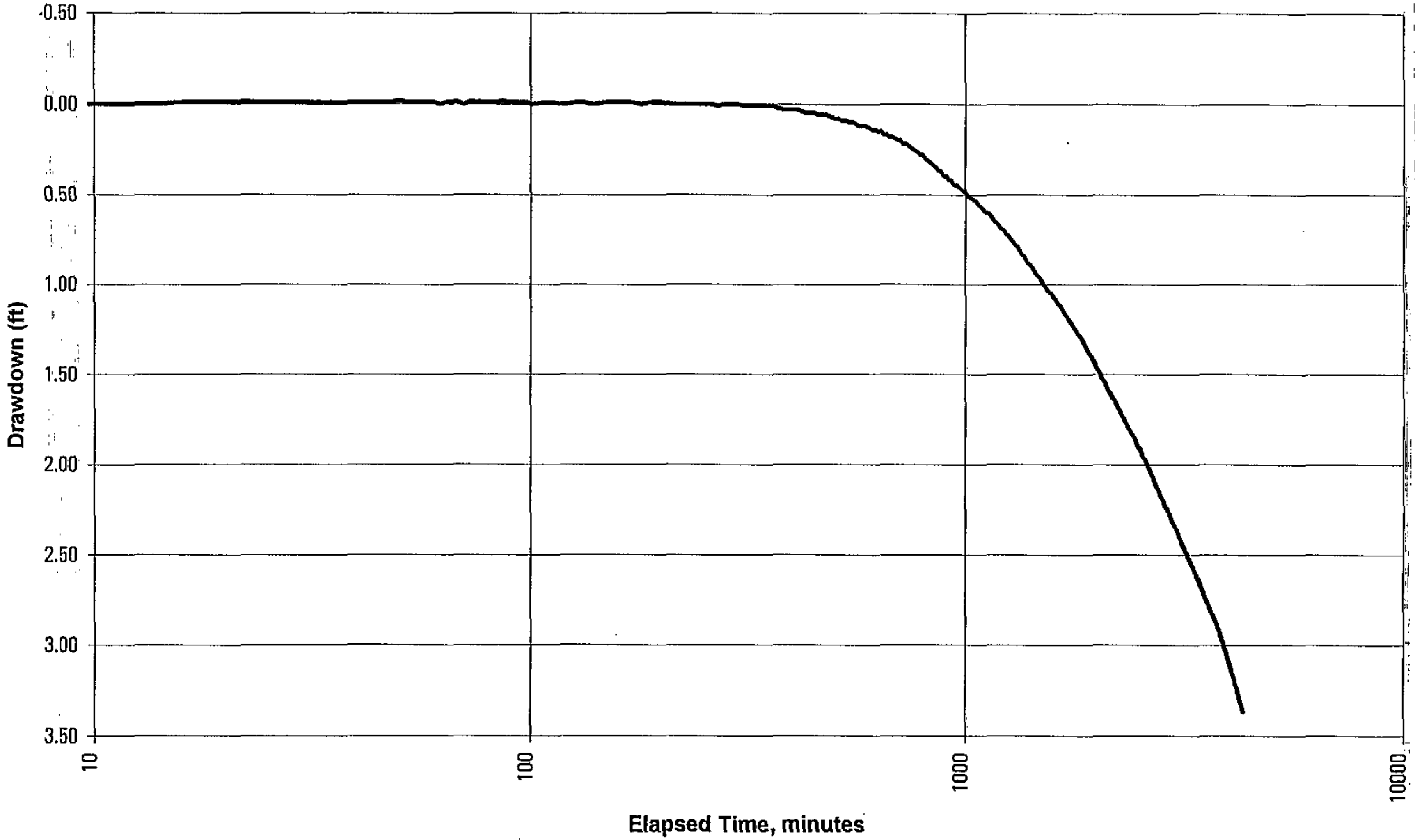
Recovery Test MID-04
Observation Well GF-303
Hand Water Level Measurements



Attachment K2
Semi-log Data Plots
Drawdown vs. Log Time

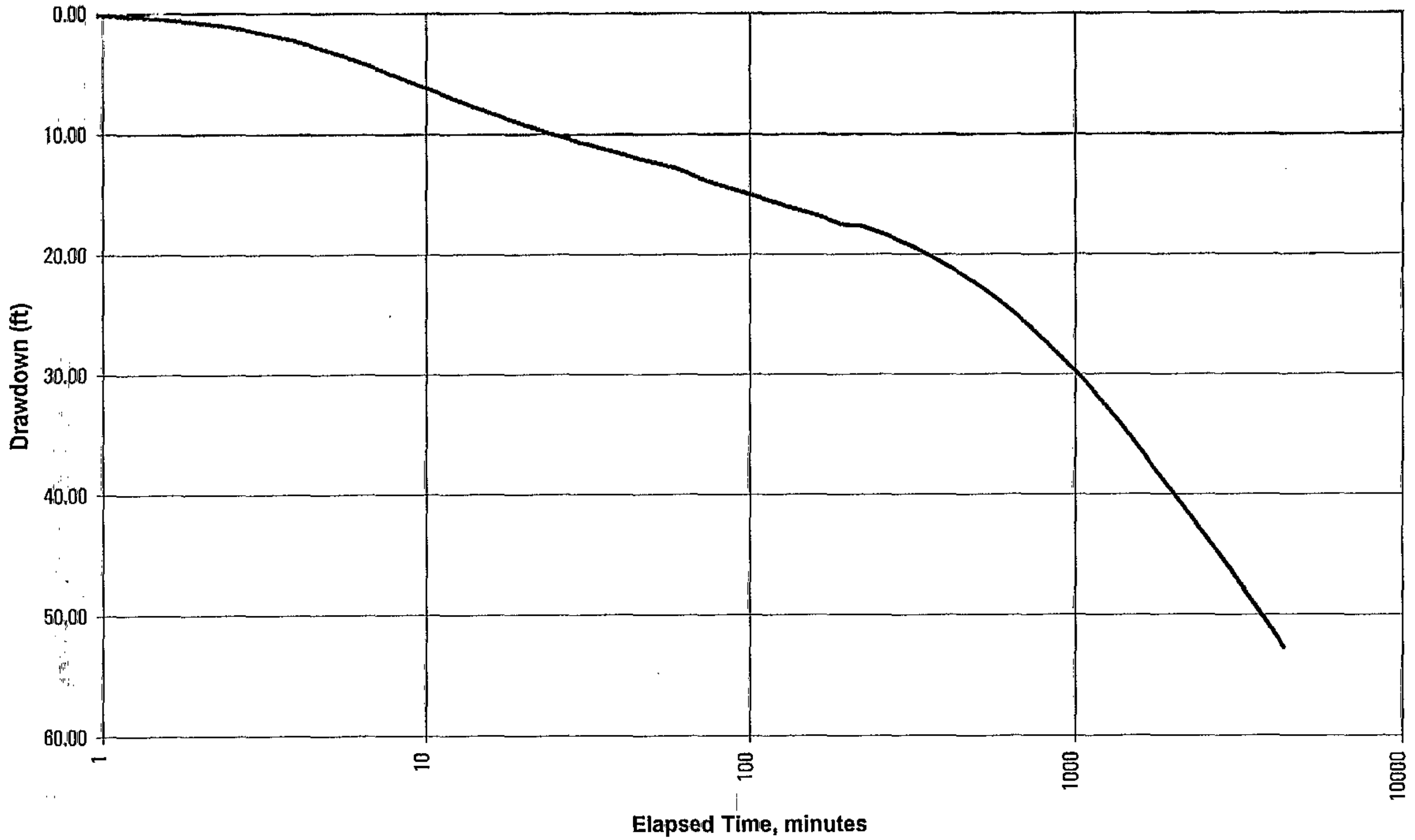
Drawdown vs. Log Time-Pumping Test HIA-2

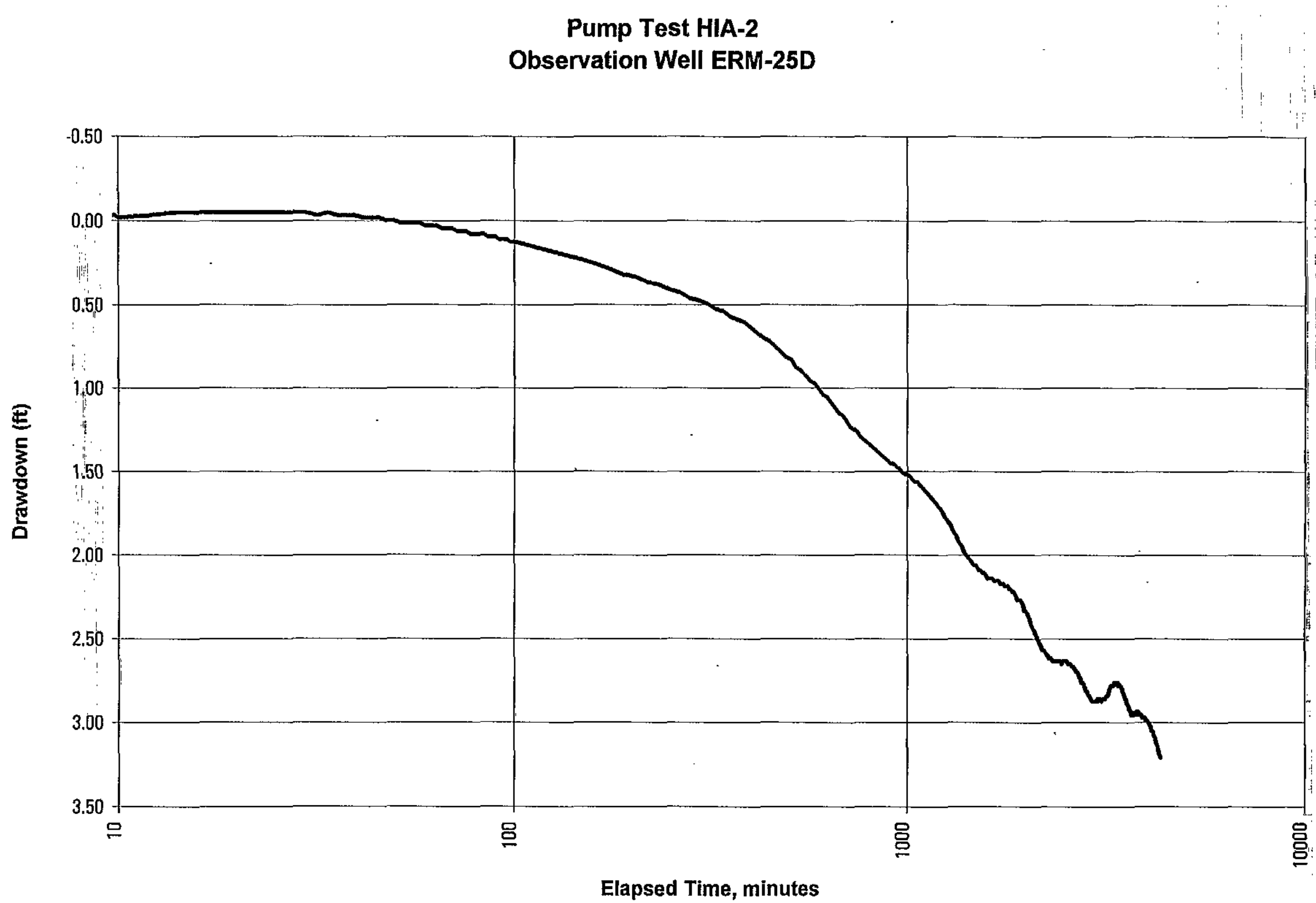
Pump Test HIA-2
Observation Well ERM-25S



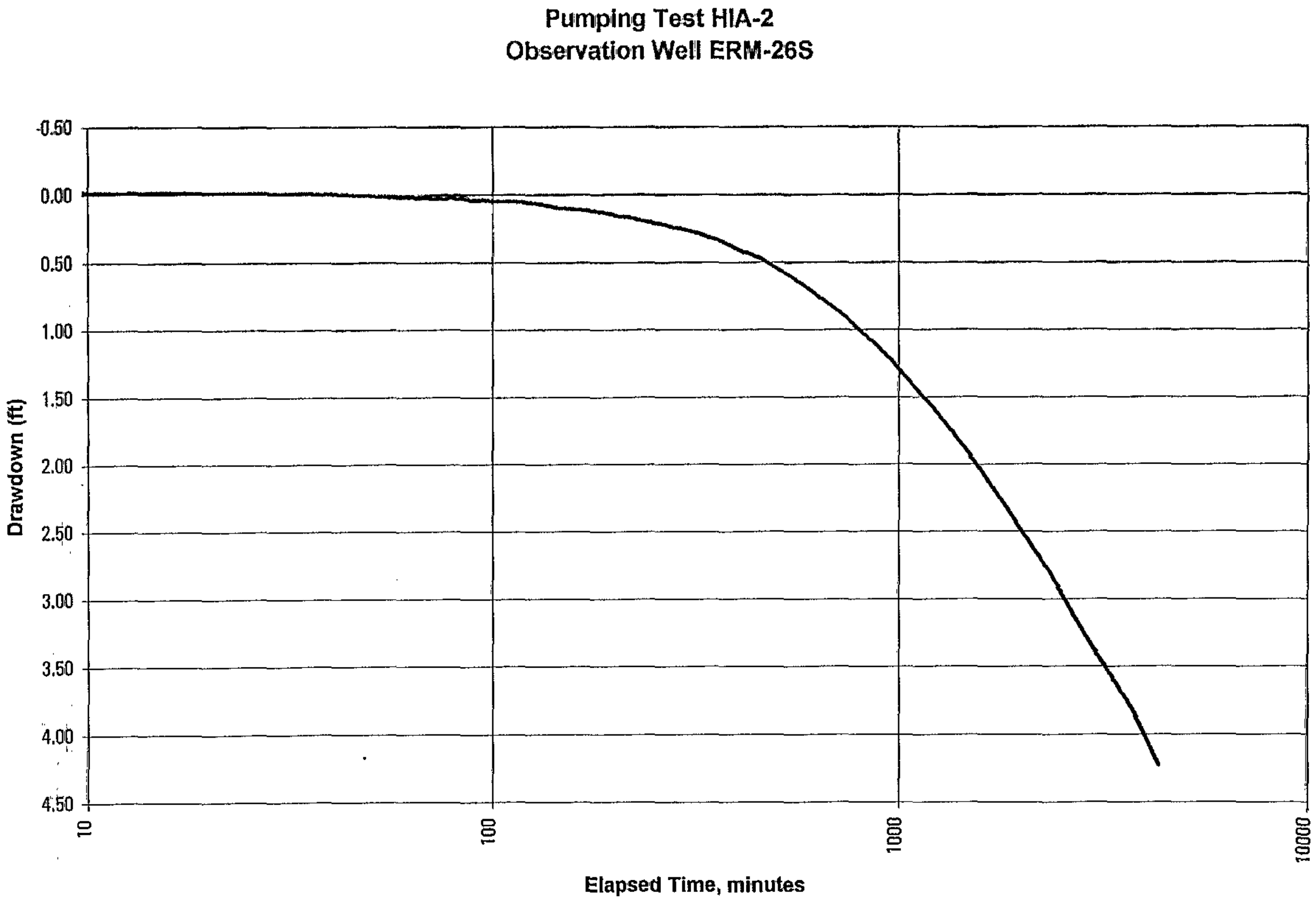
Filename: 25IHIA2.XLW
Date Printed: 12/20/95

Pump Test HIA-2
Observation Well ERM-25I

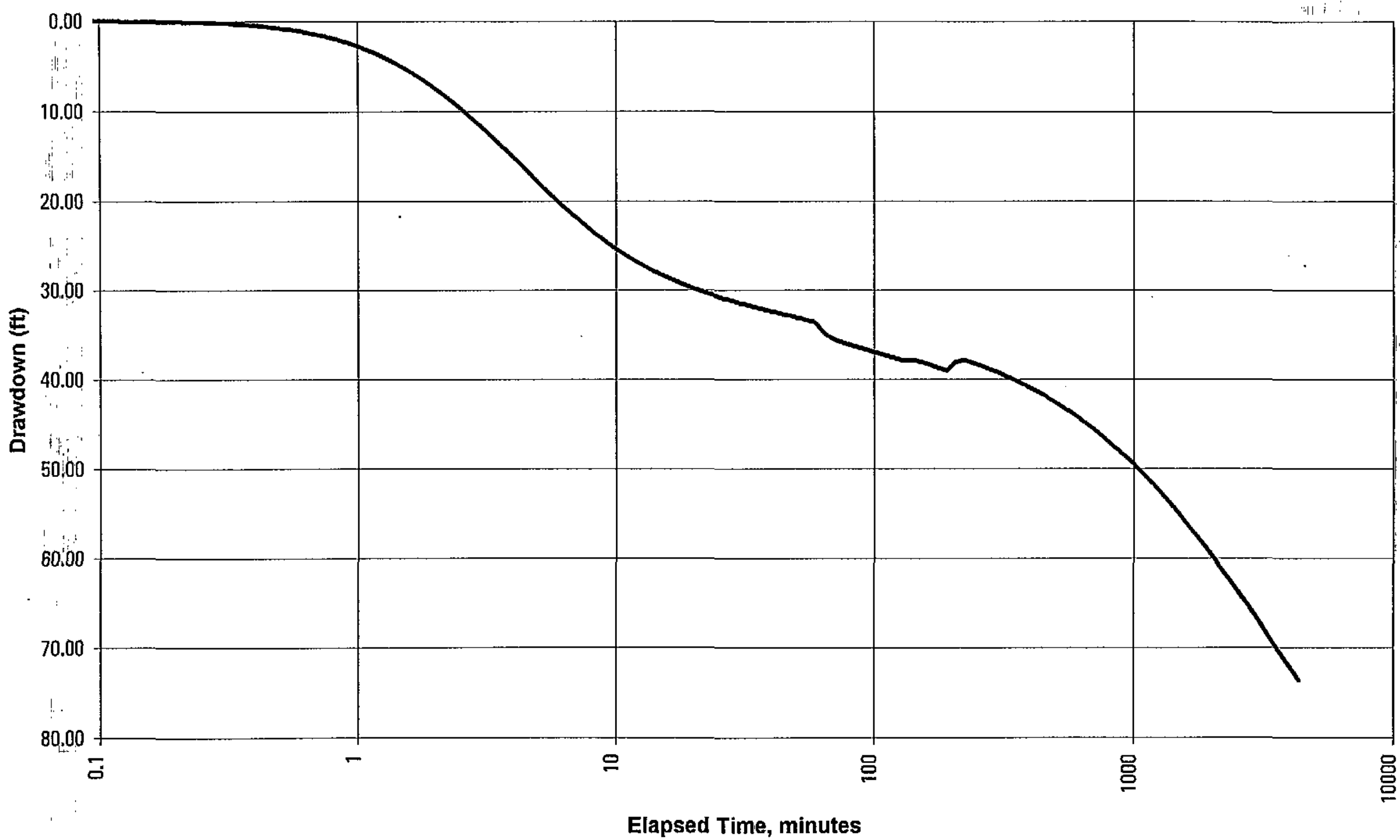



Pump Test HIA-2
Observation Well ERM-25D
Drawdown (ft)
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
10
100
1000
10000
Elapsed Time, minutes

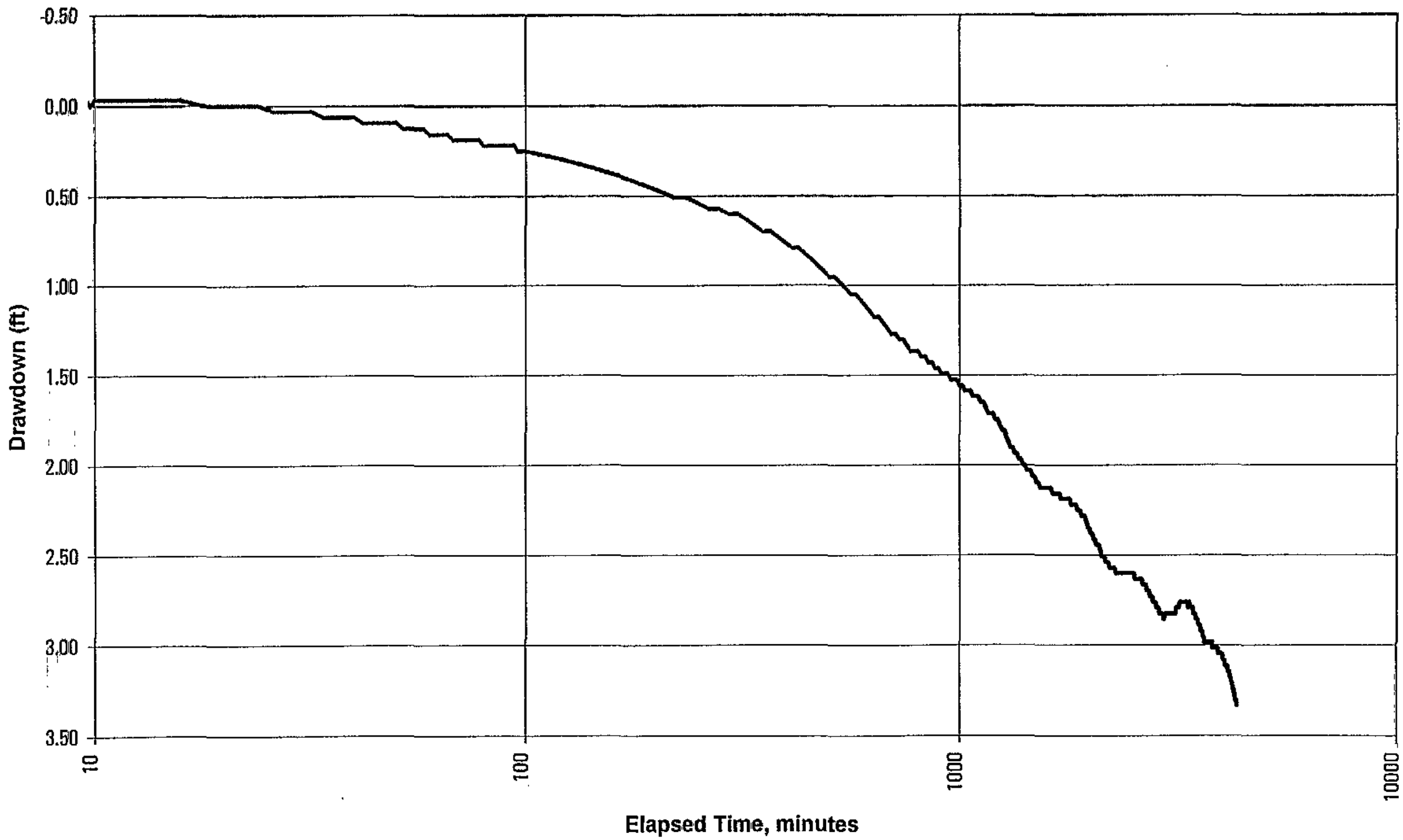
Filename: 26SHIA2.XLW
Date Printed: 12/20/95



Pumping Test HIA-2
Observation Well ERM-26I



Pumping Test HIA-2
Observation Well ERM-26D



Filena 0HIA2.XLW
Date Printed: 12/20/95

Pump Test HIA-2
Observation Well GF-210

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Filename: 310HIA2.XLW
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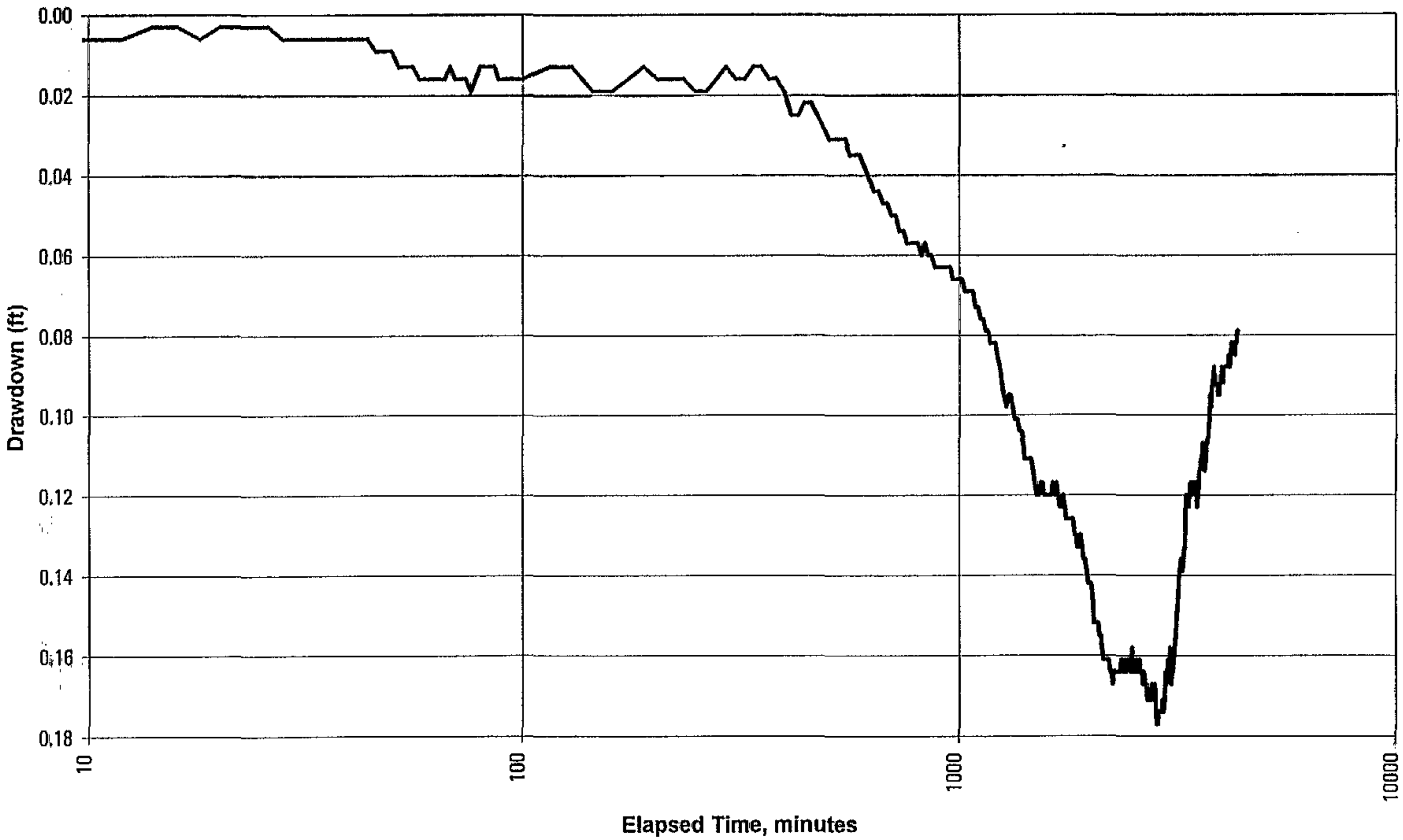
Pumping Test HIA-2
Observation Well GF-310



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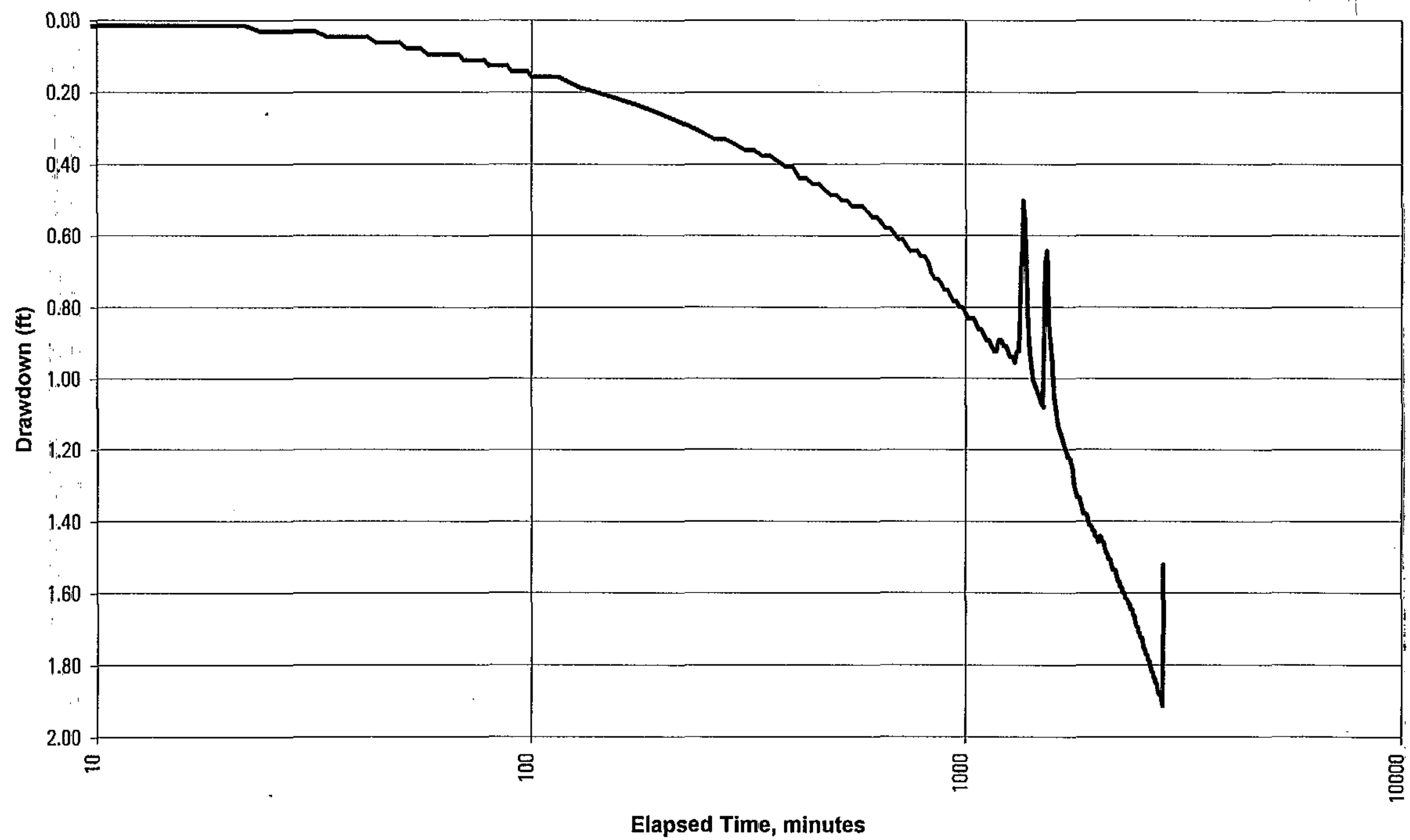
Pumping Test HIA-2
Observation Well GF-311



THE ERM GROUP

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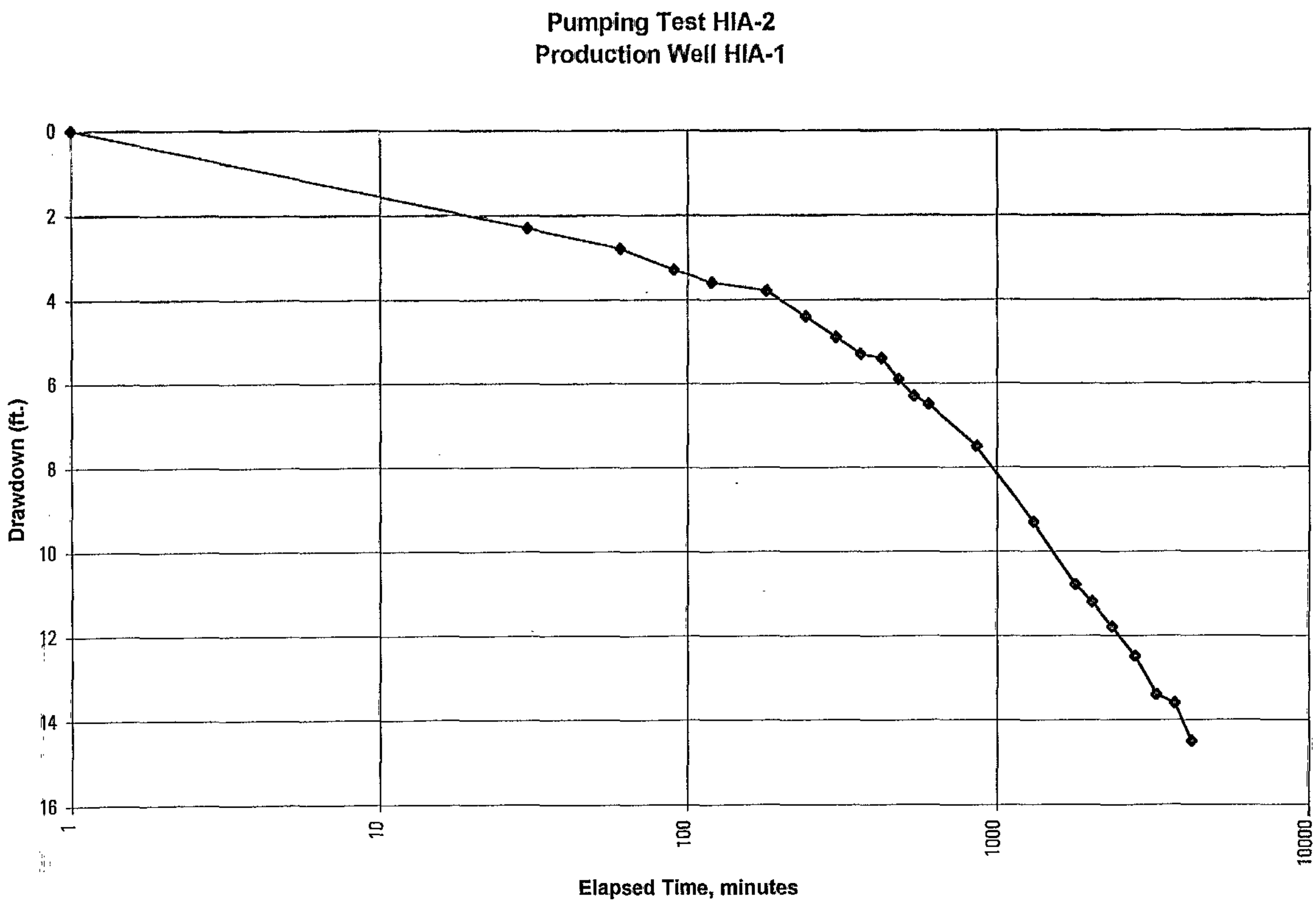

THE ERM GROUP

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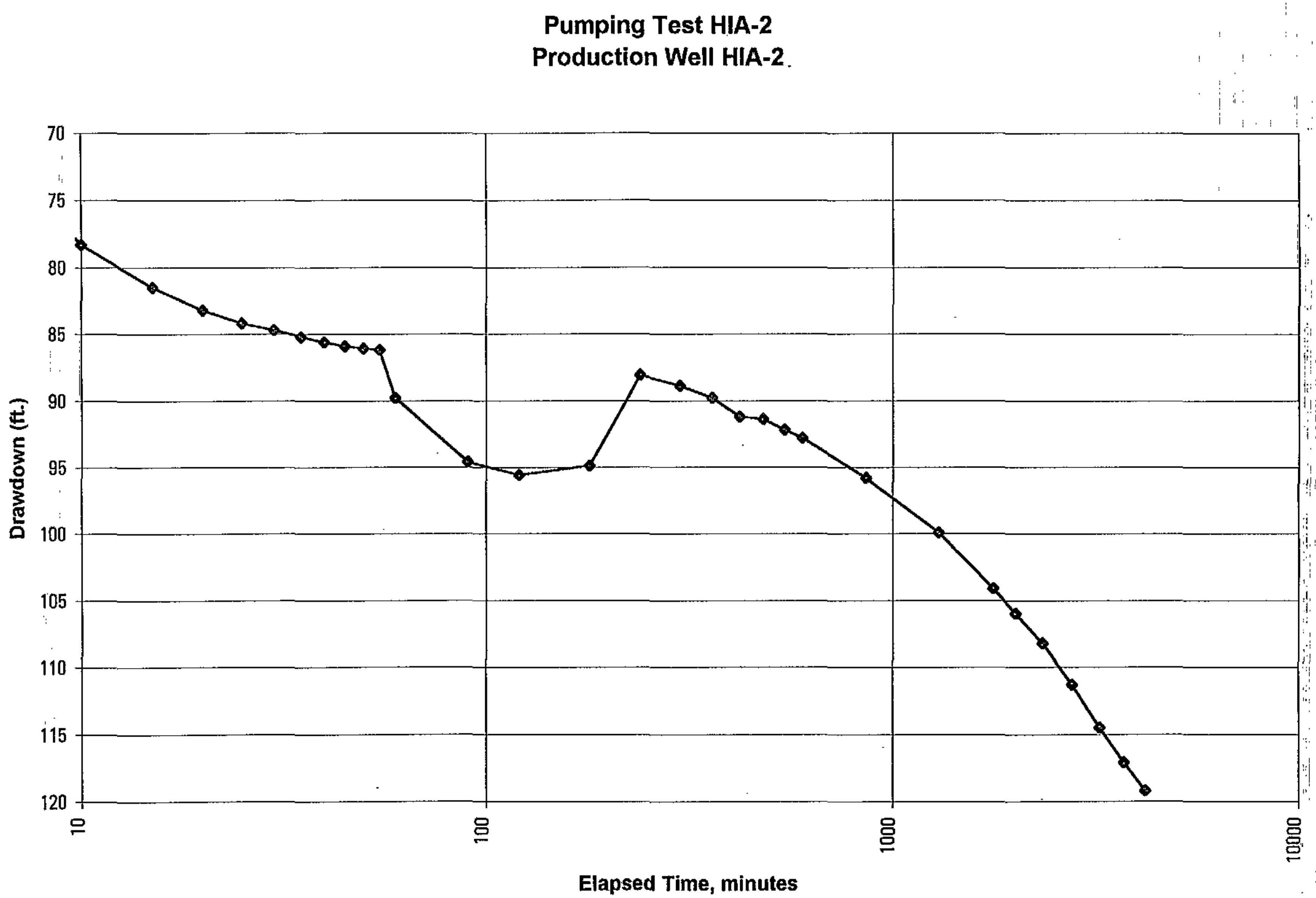

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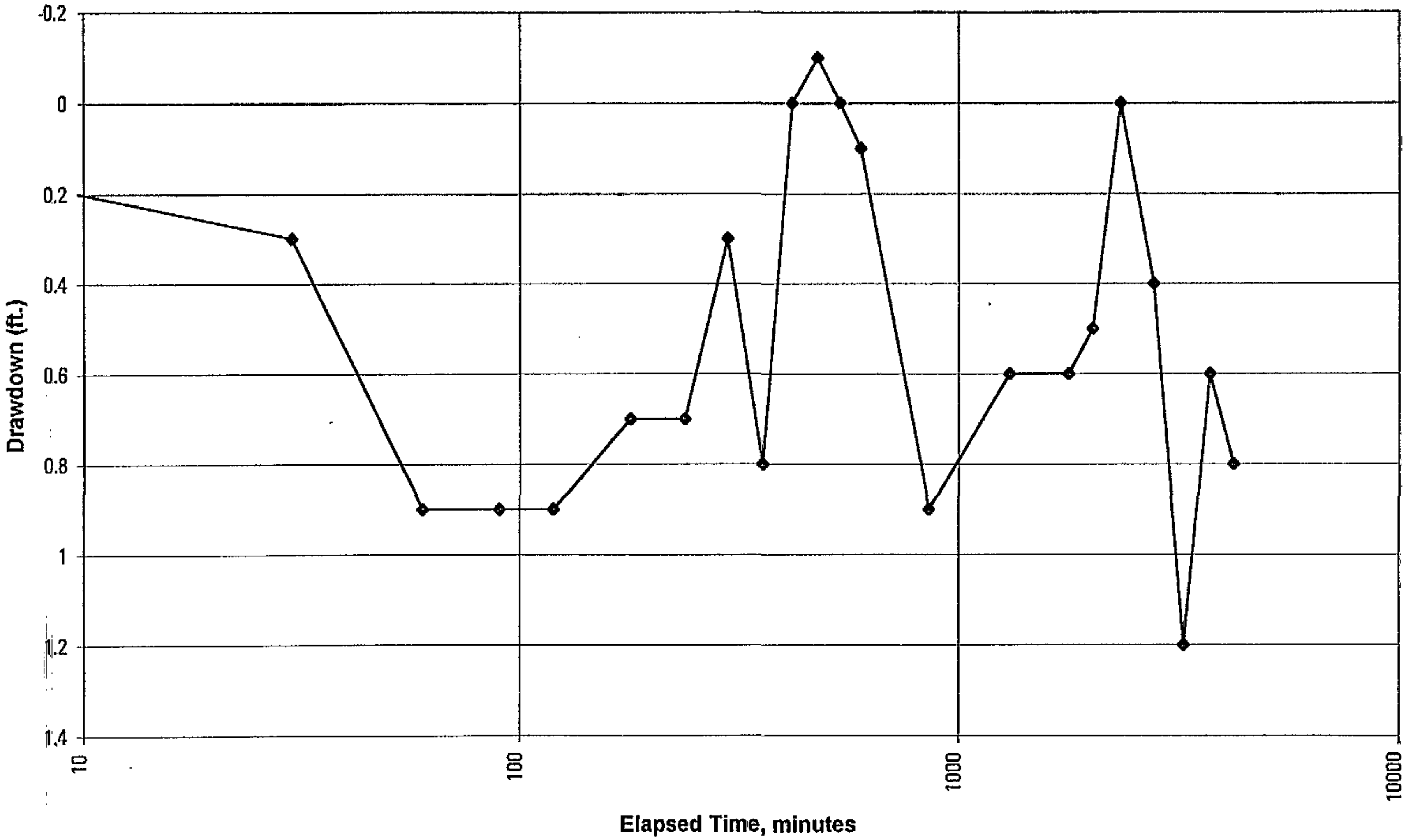
Pumping Test HIA-2
Production Well HIA-3



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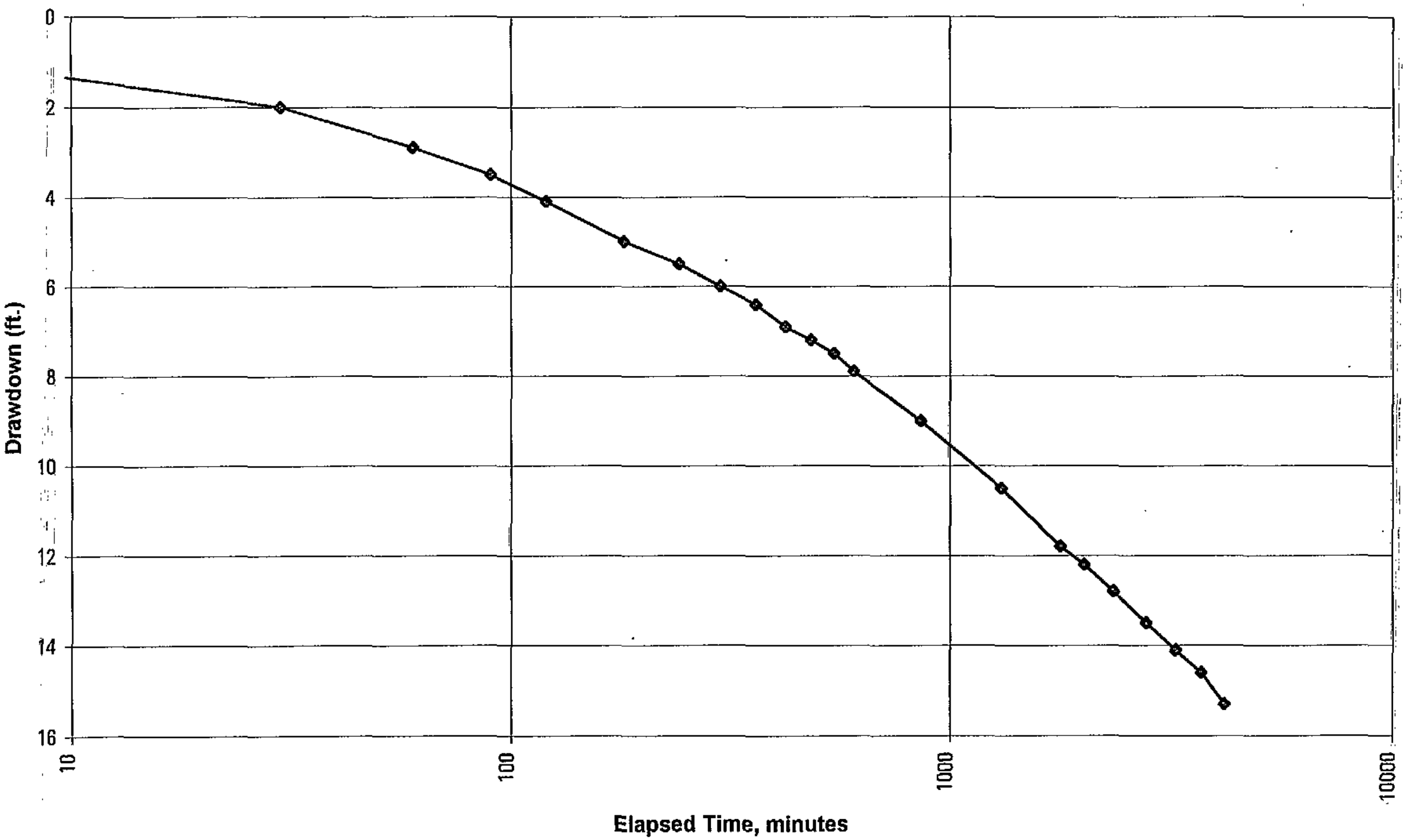
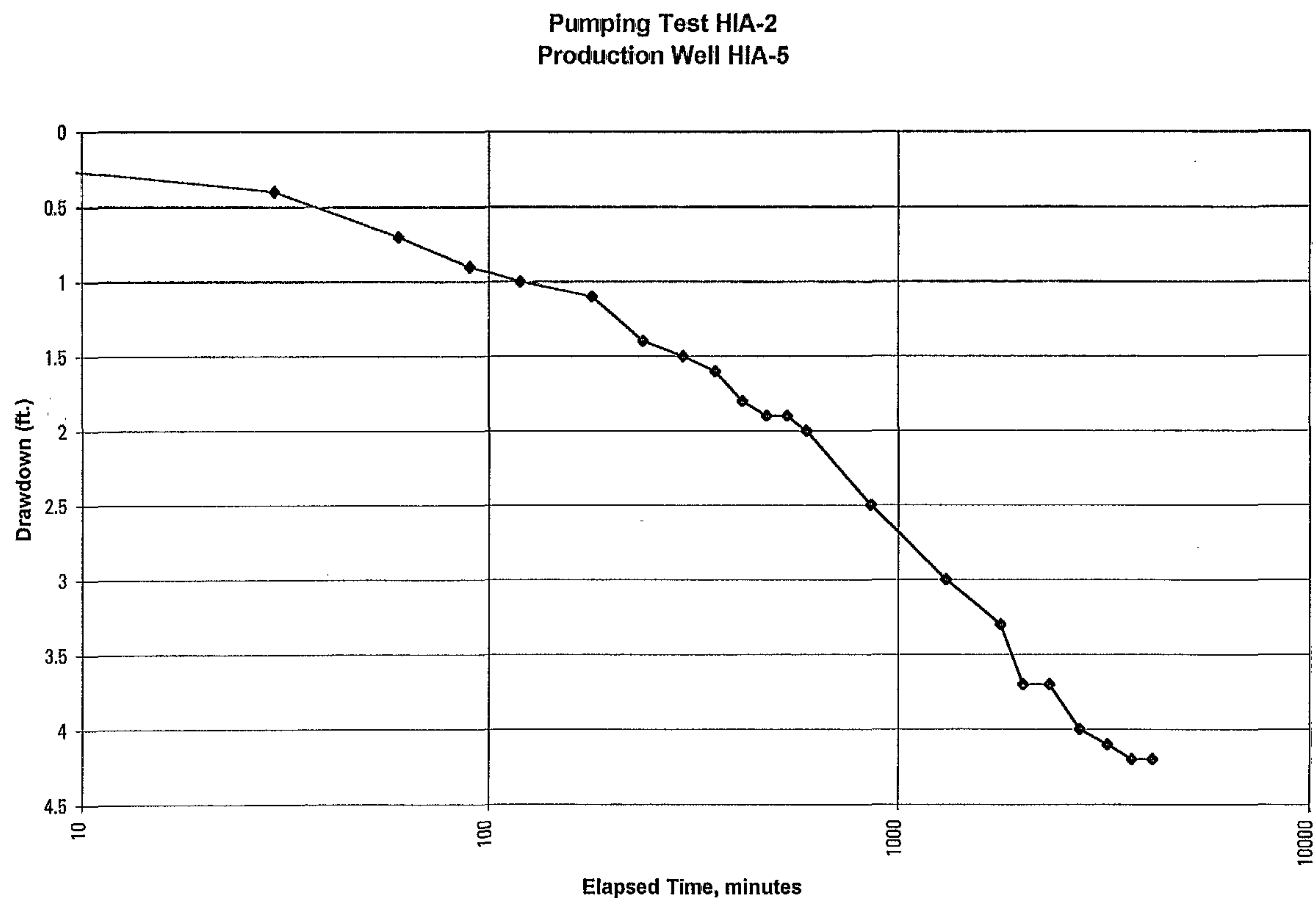
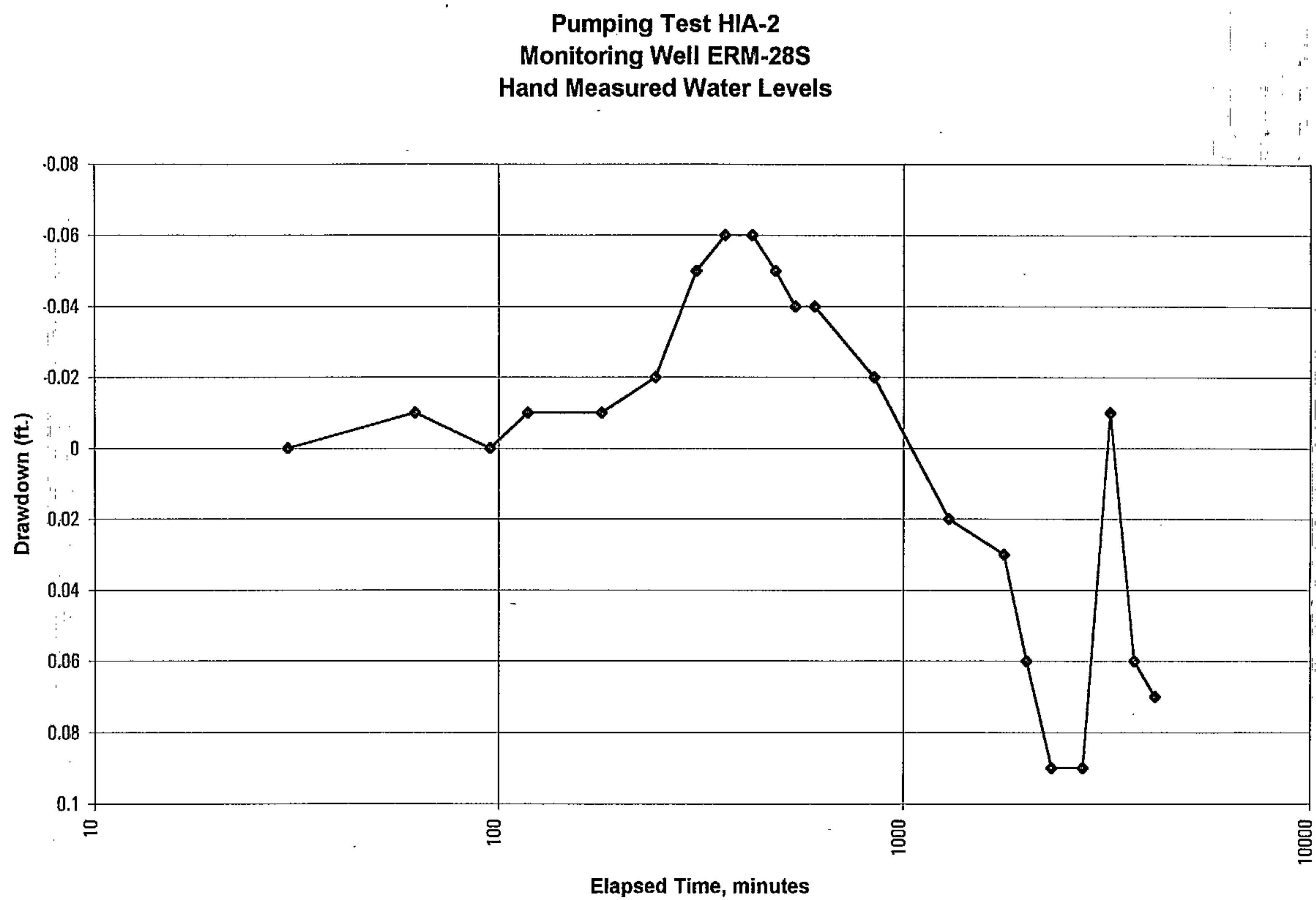
Pumping Test HIA-2
Production Well HIA-4

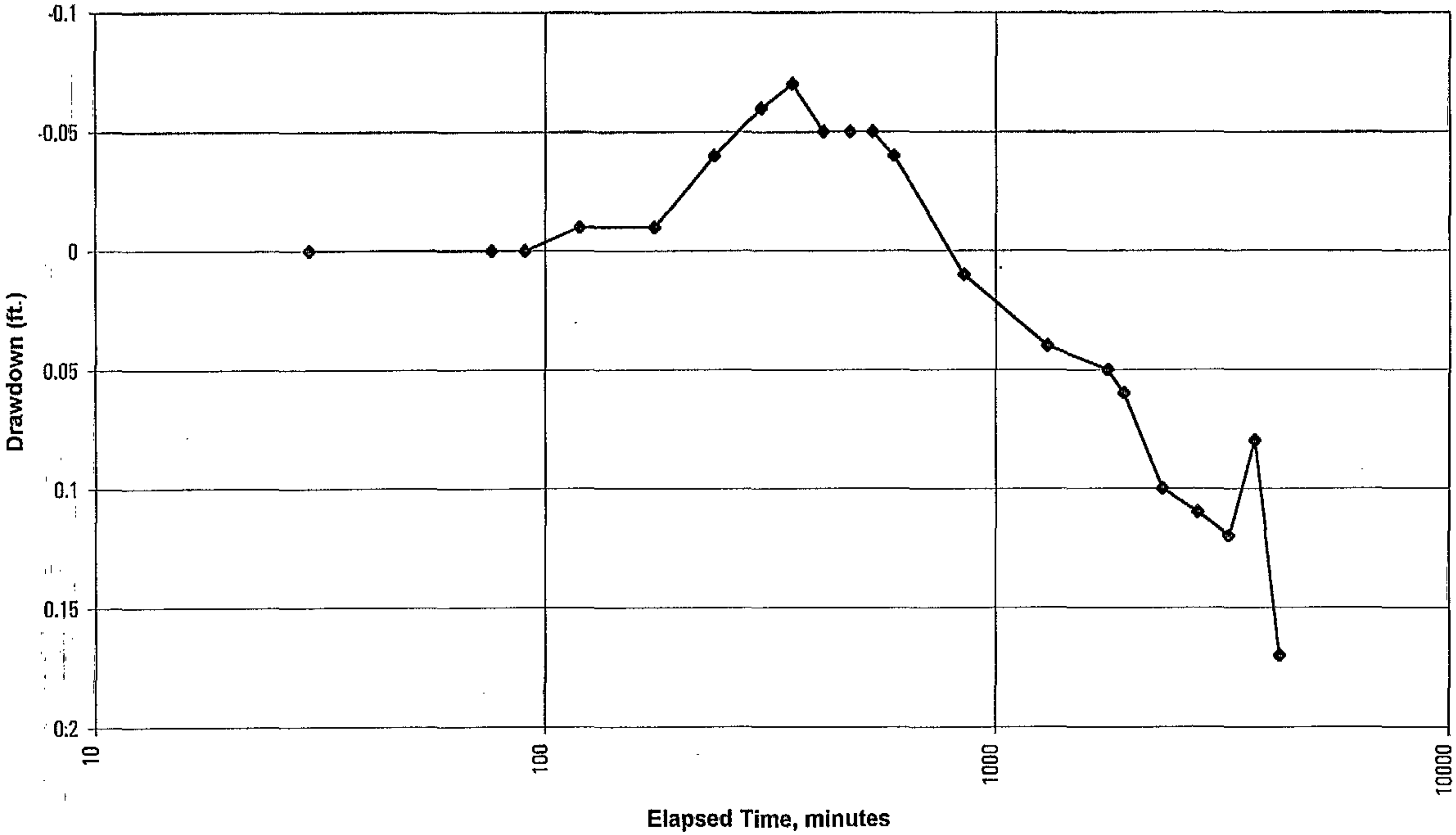


THE ERM GROUP


Pumping Test HIA-2
Production Well HIA-5
Drawdown (ft.)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
10
100
1000
10000
Elapsed Time, minutes

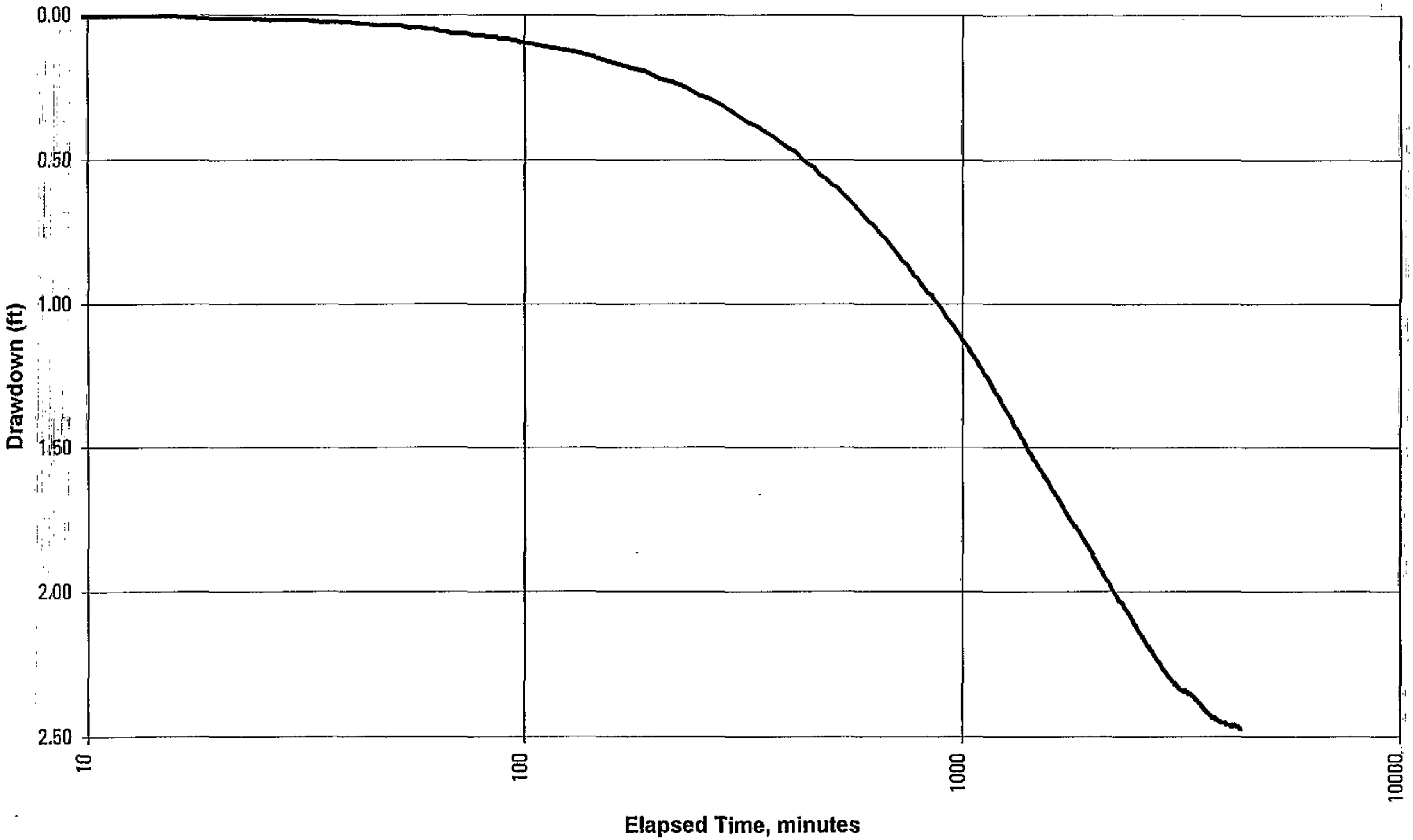

Pumping Test HIA-2
Monitoring Well ERM-28S
Hand Measured Water Levels
Drawdown (ft.)
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
10
100
1000
10000
Elapsed Time, minutes

Pumping Test HIA-2
Monitoring Well GF-227
Hand Measured Water Levels

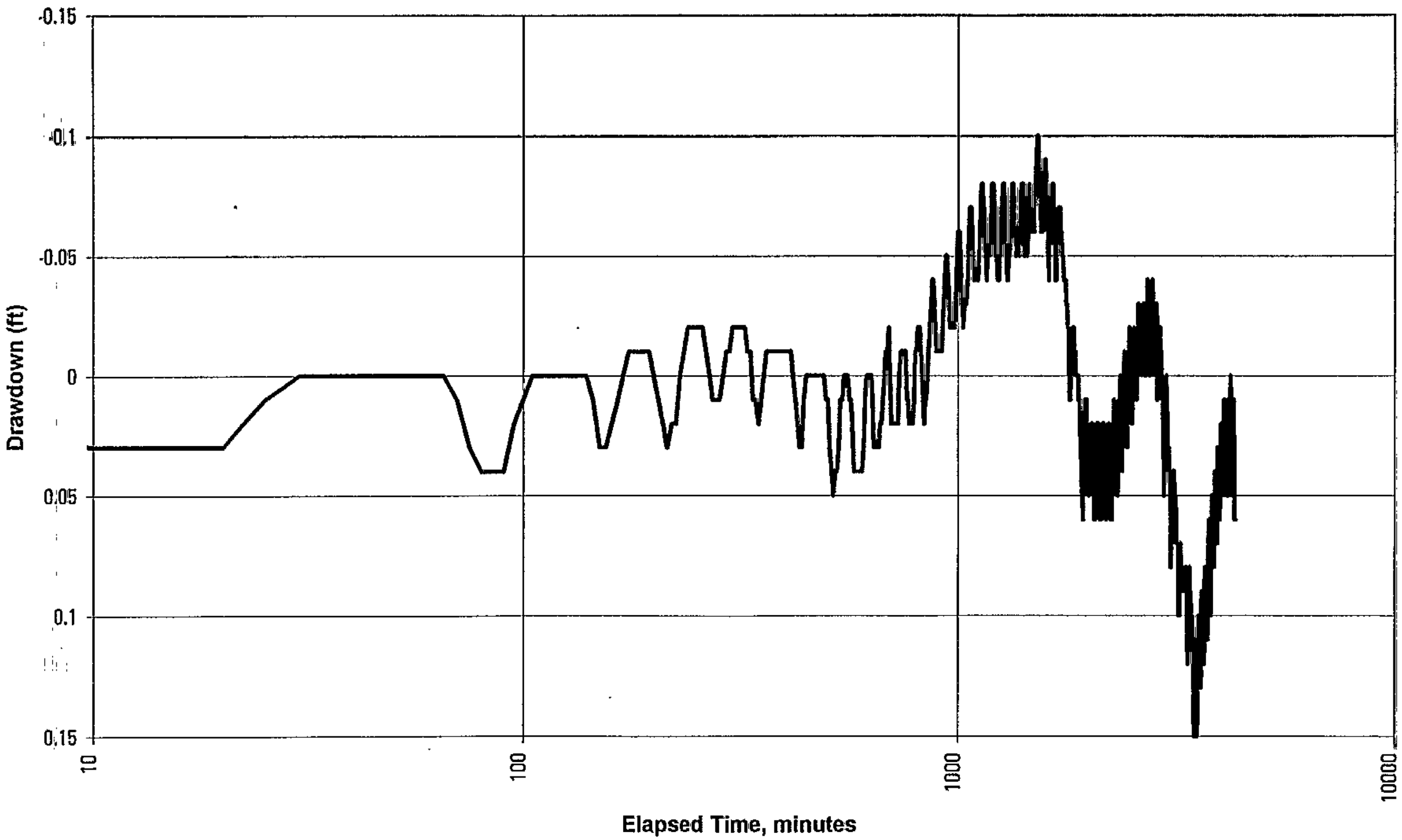


Drawdown vs. Log Time-Pumping Test HIA-9

Pumping Test HIA-9
Monitoring Well GF-314

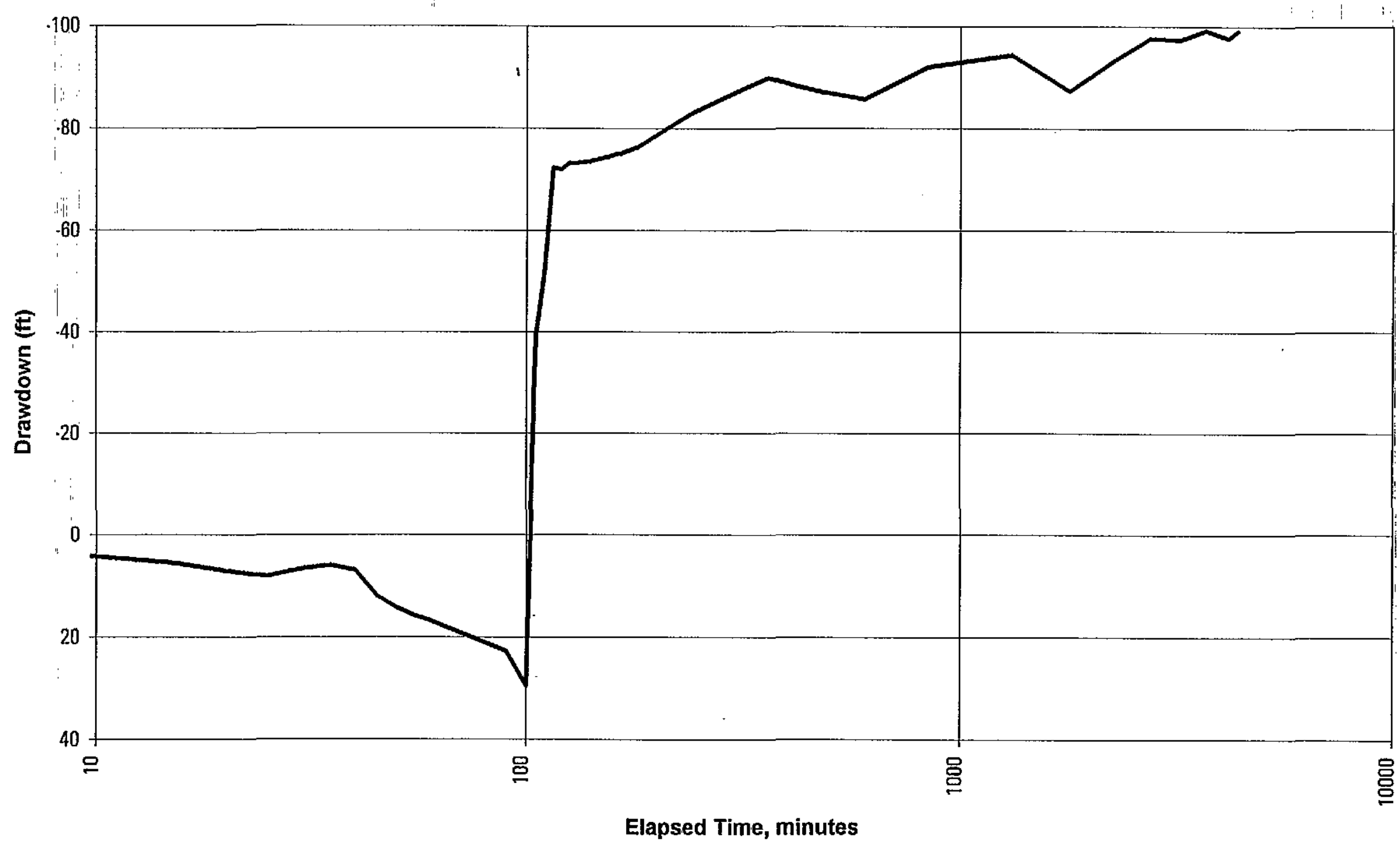


Pumping Test HIA-9
Monitoring Well ERM-10I

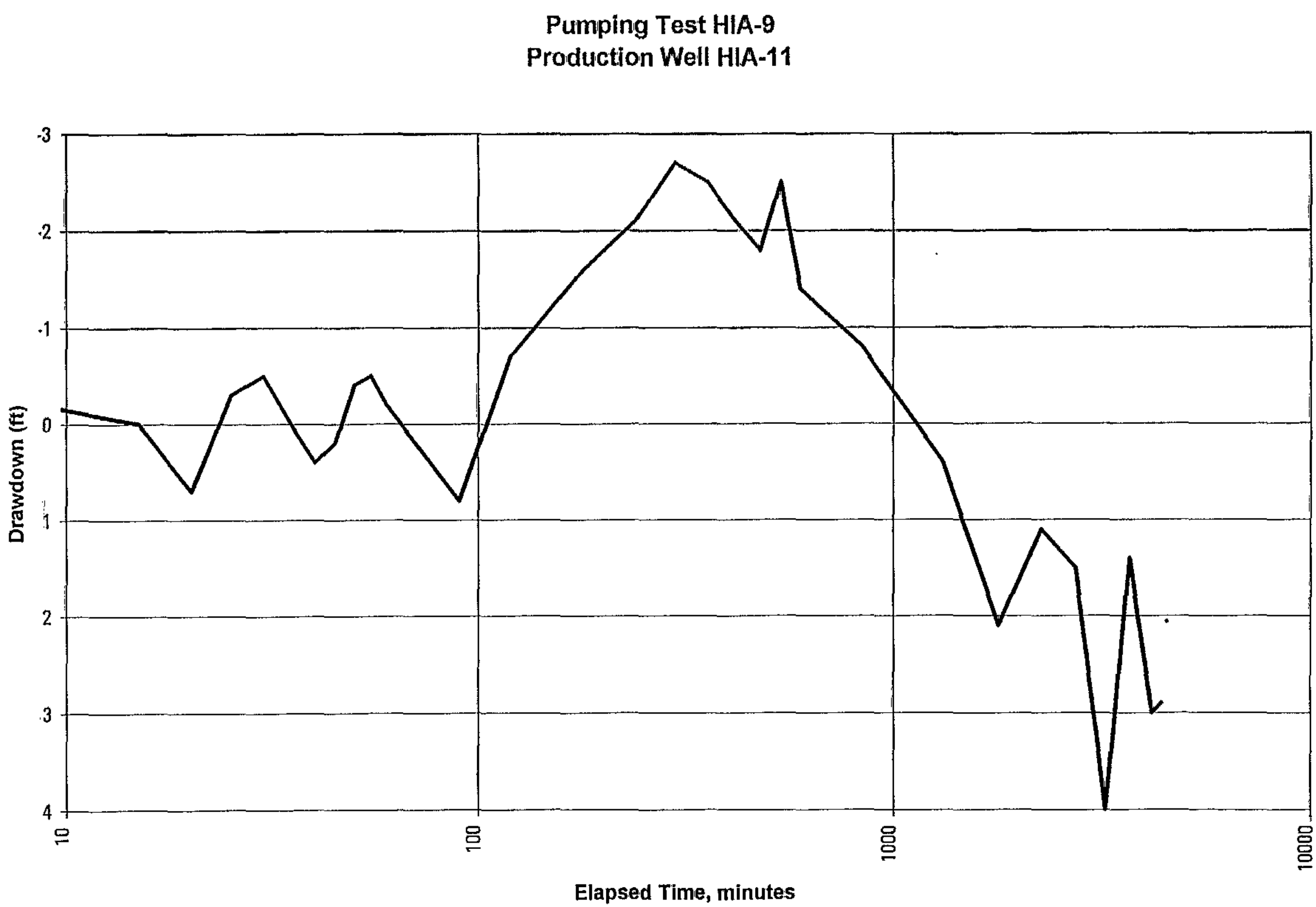


Filename: _SUBM.XLW
Date Printed: 12/20/95

Pumping Test HIA-9
Production Well HIA-6



Filename: H9_SUBM.XLW
Date Printed: 12/20/95



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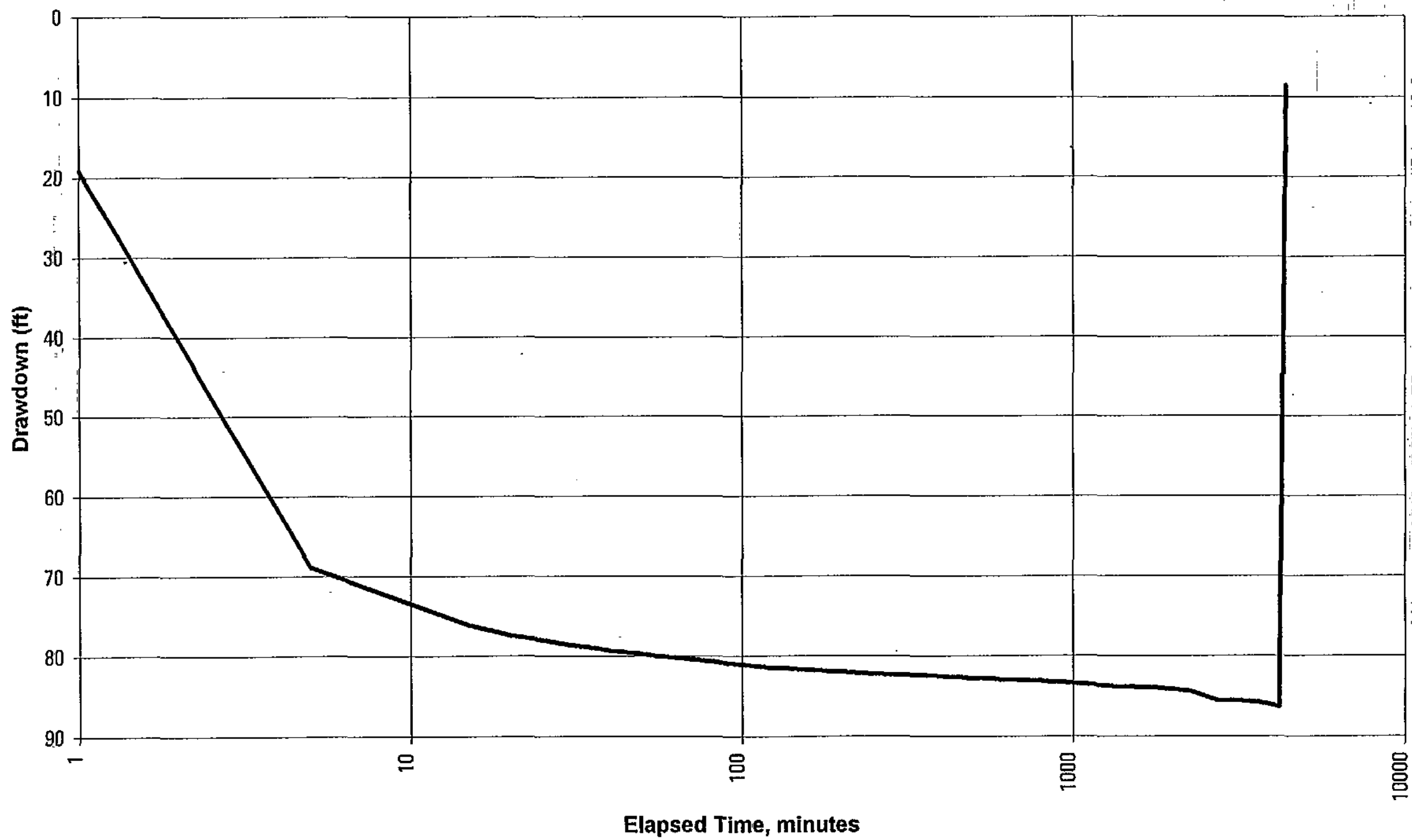
Pumping Test HIA-9
Production Well HIA-9



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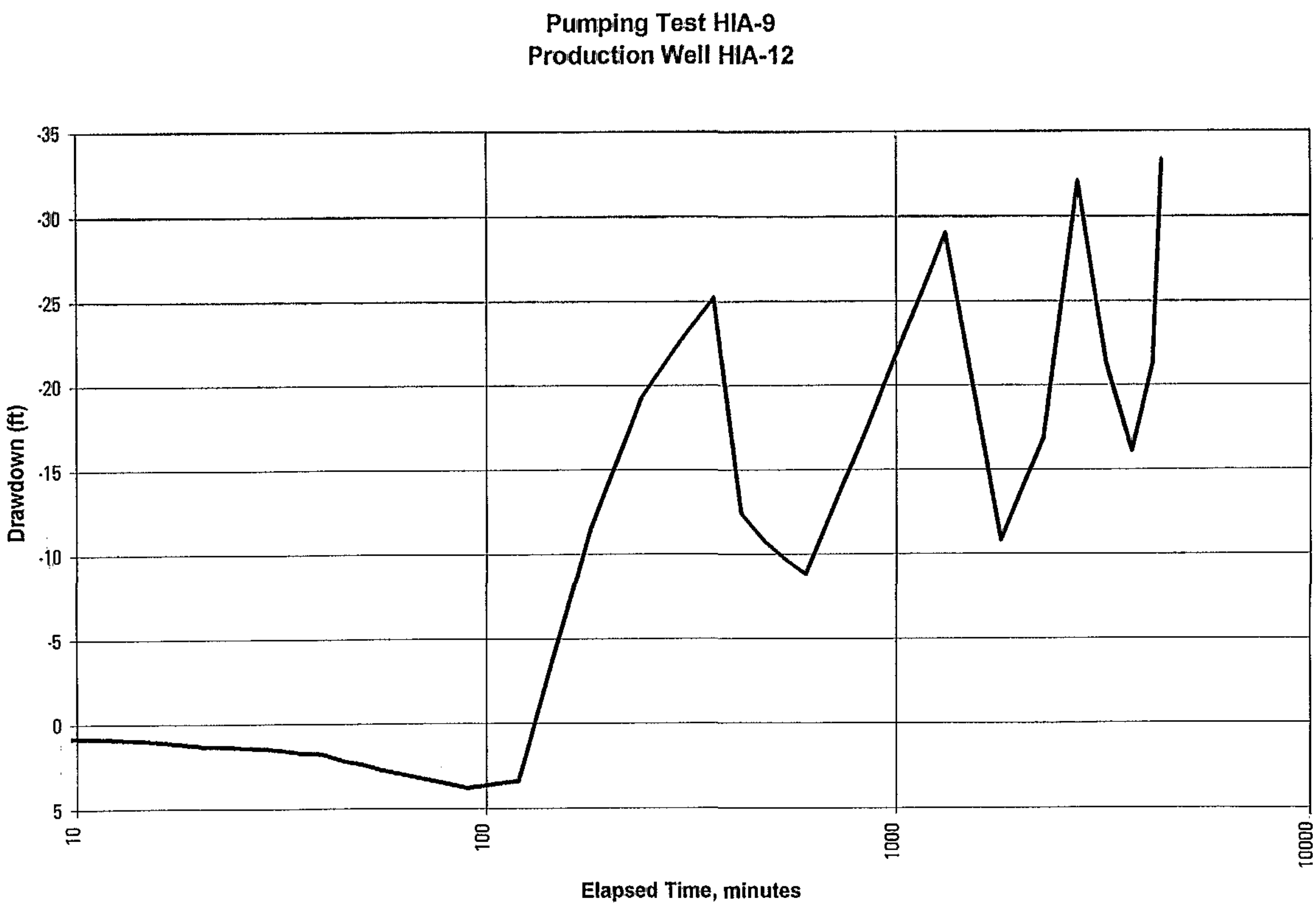
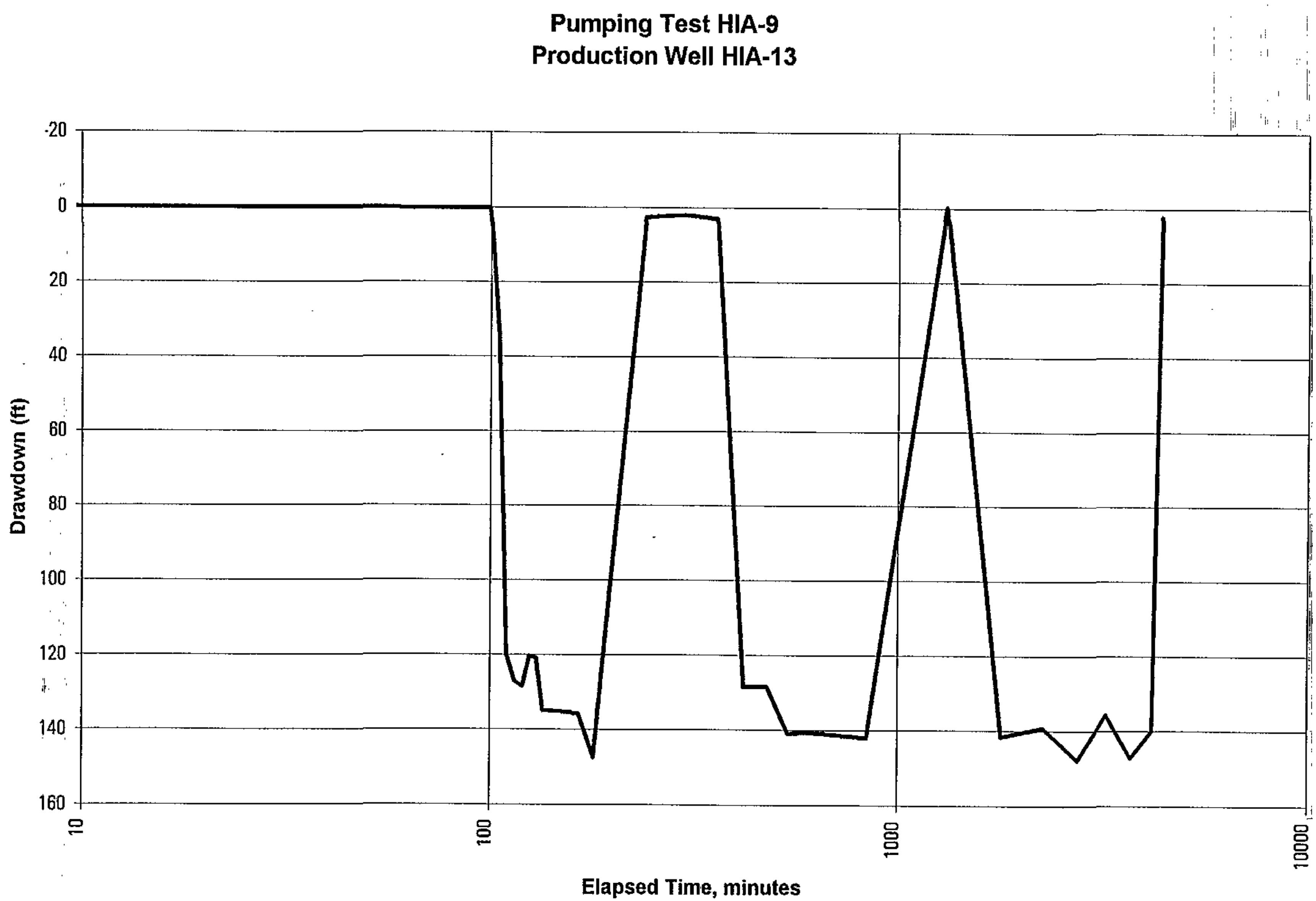
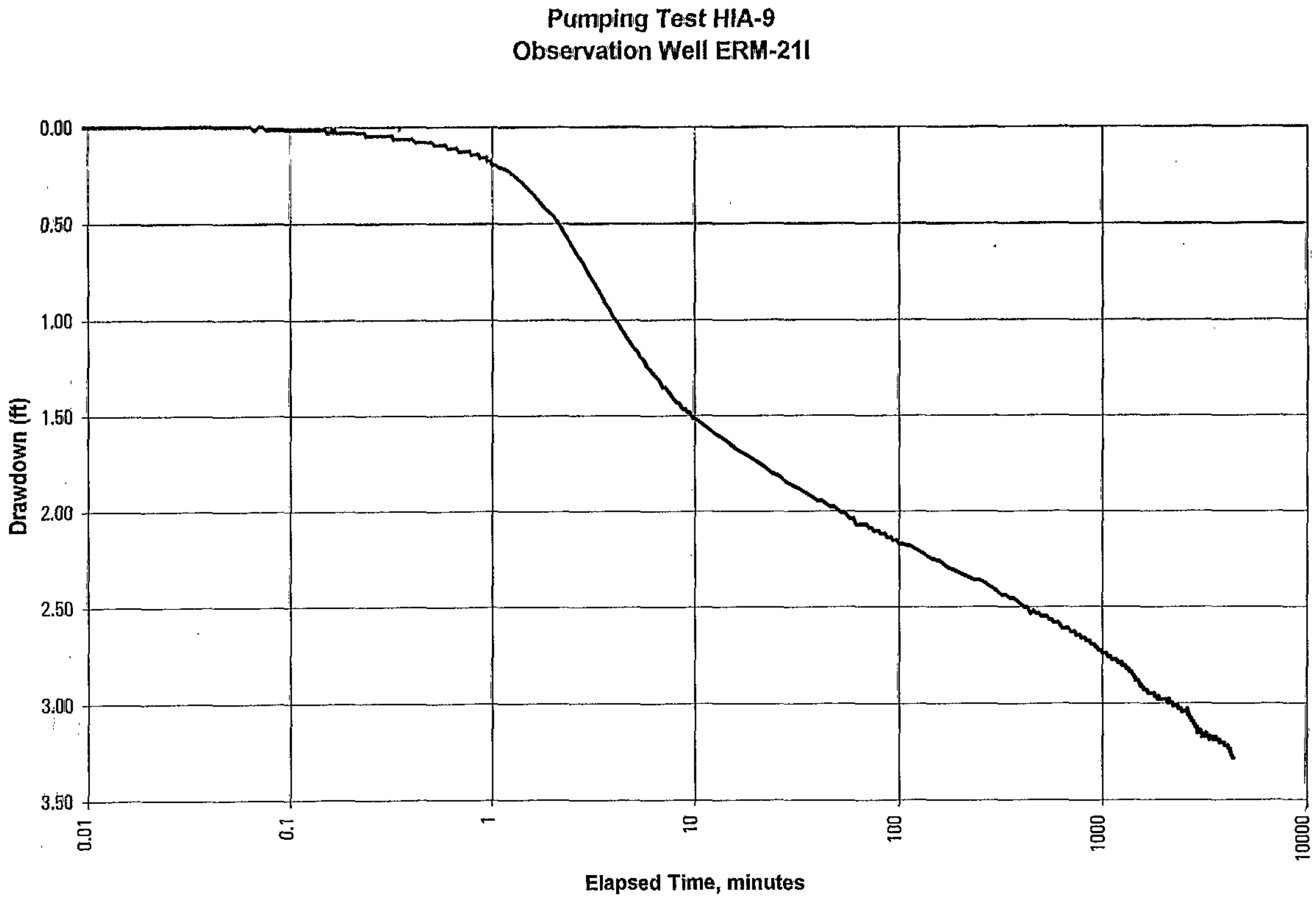


THE ERM GROUP


Pumping Test HIA-9
Production Well HIA-13
Drawdown (ft)
-20
0
20
40
60
80
100
120
140
160
10
100
1000
10000
Elapsed Time, minutes

Filename: REV_21ID.XLW
Date Printed: 12/20/95



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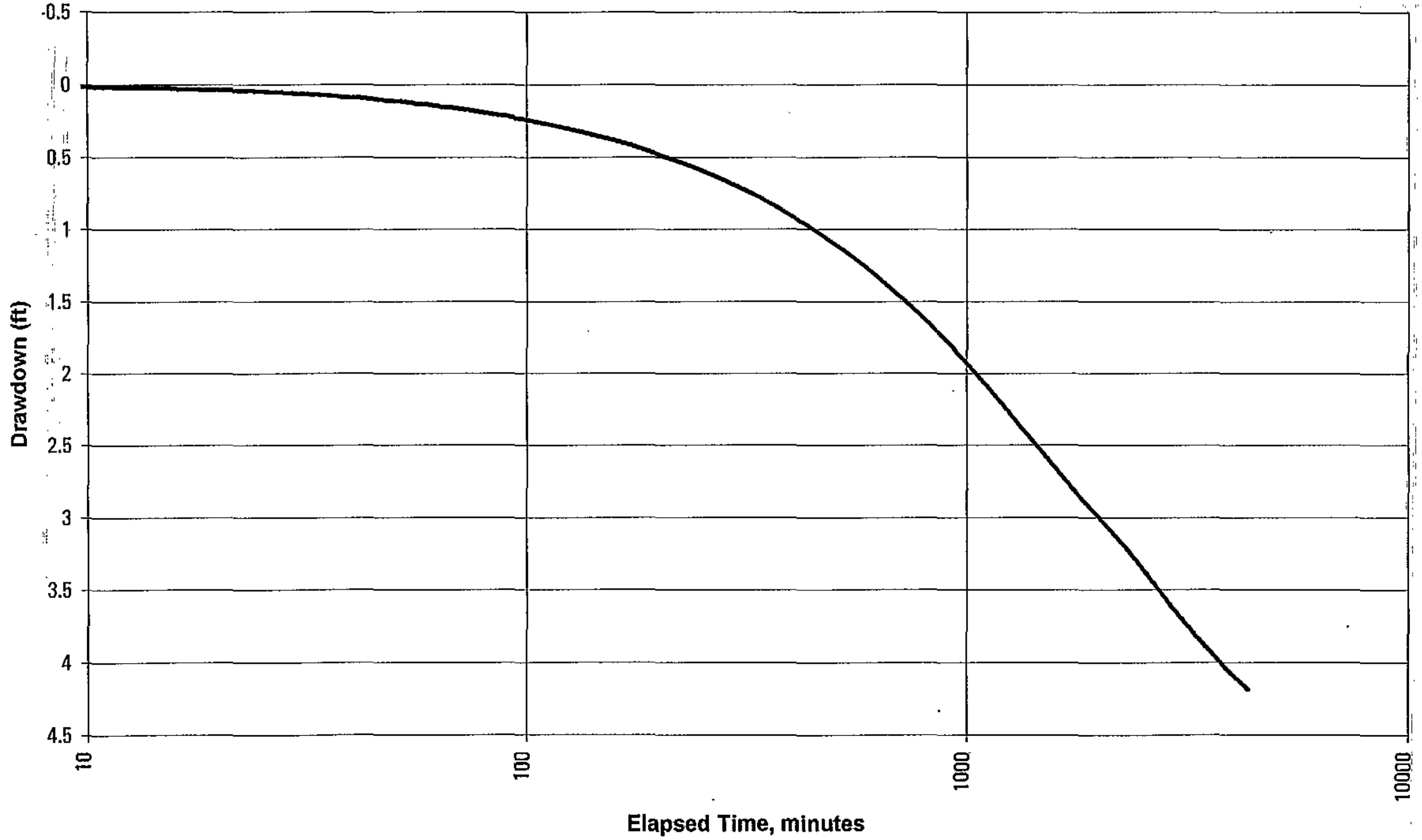
Filenam... _21S.XLW
Date Printed: 12/20/95

Pumping Test HIA-9
Observation Well ERM-21S



THE ERM GROUP

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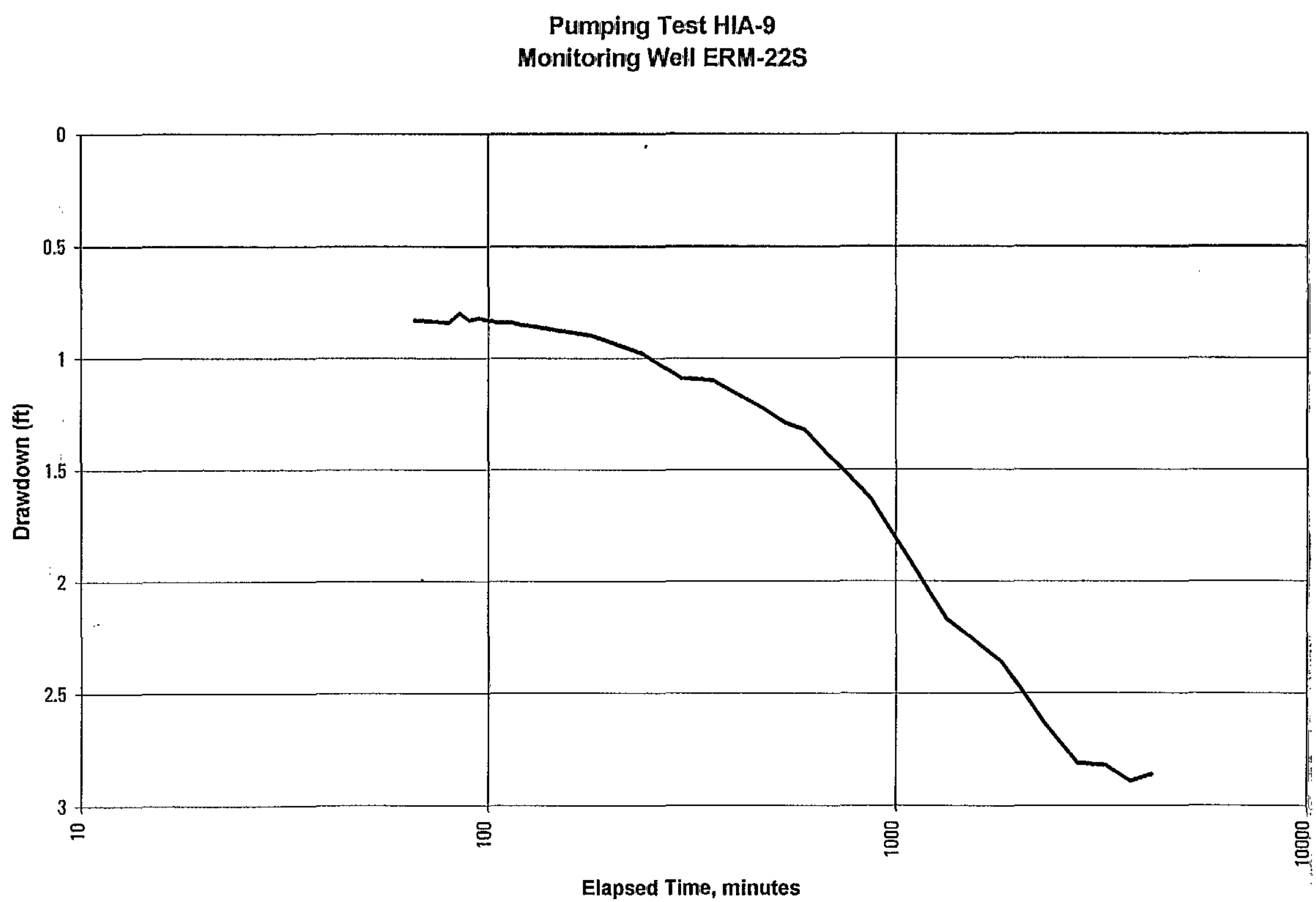
Date Printed: 12/20/95



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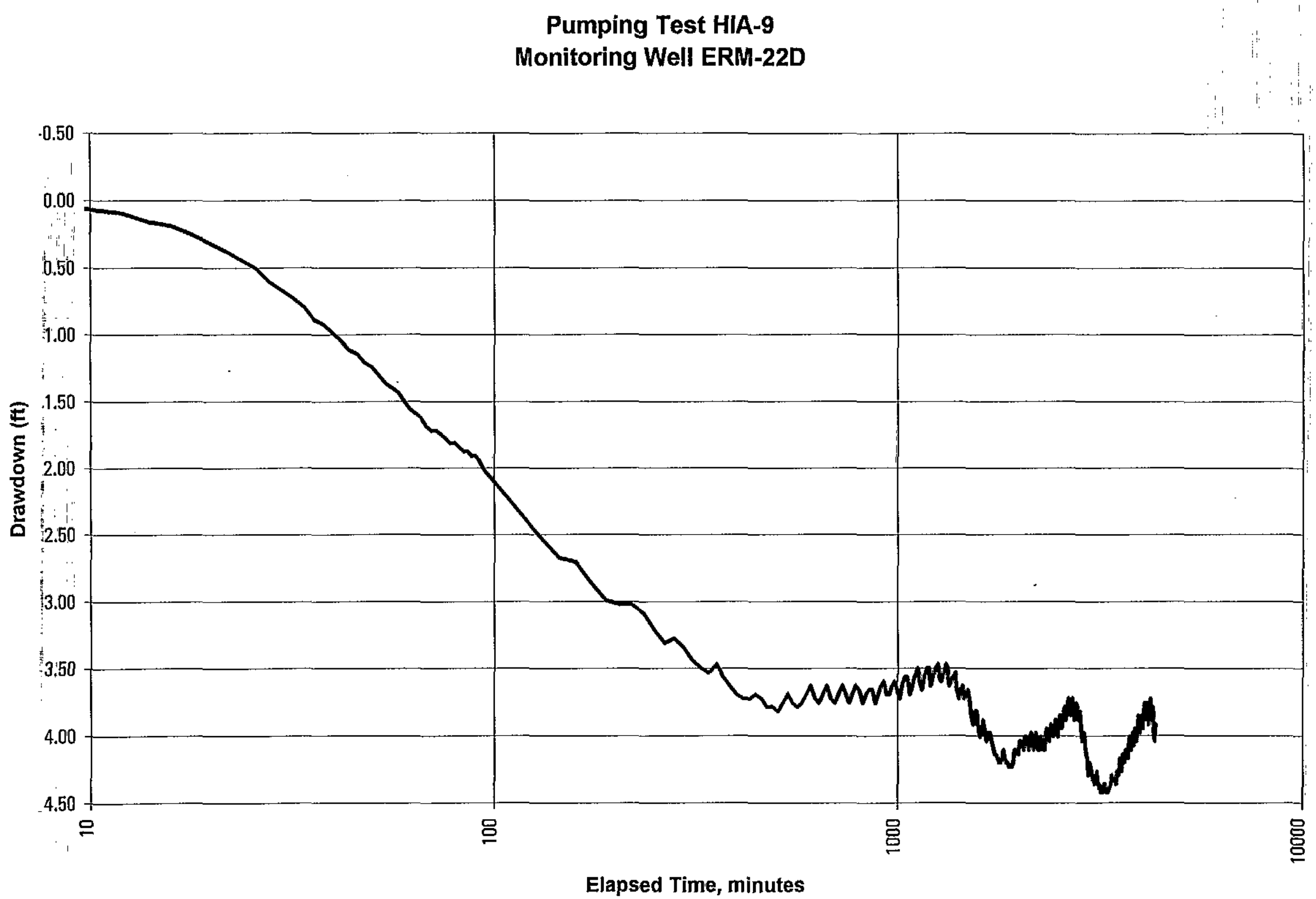
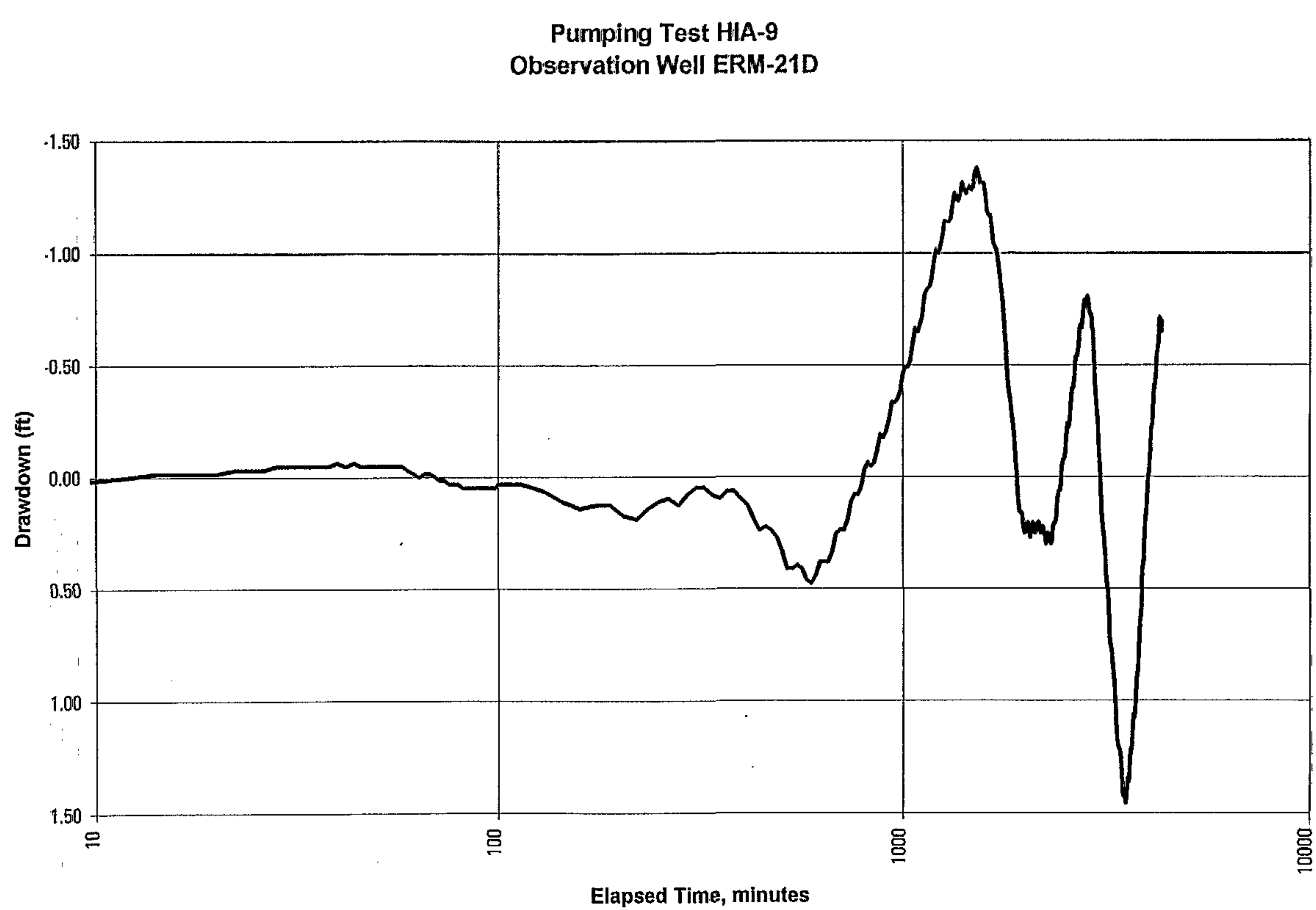
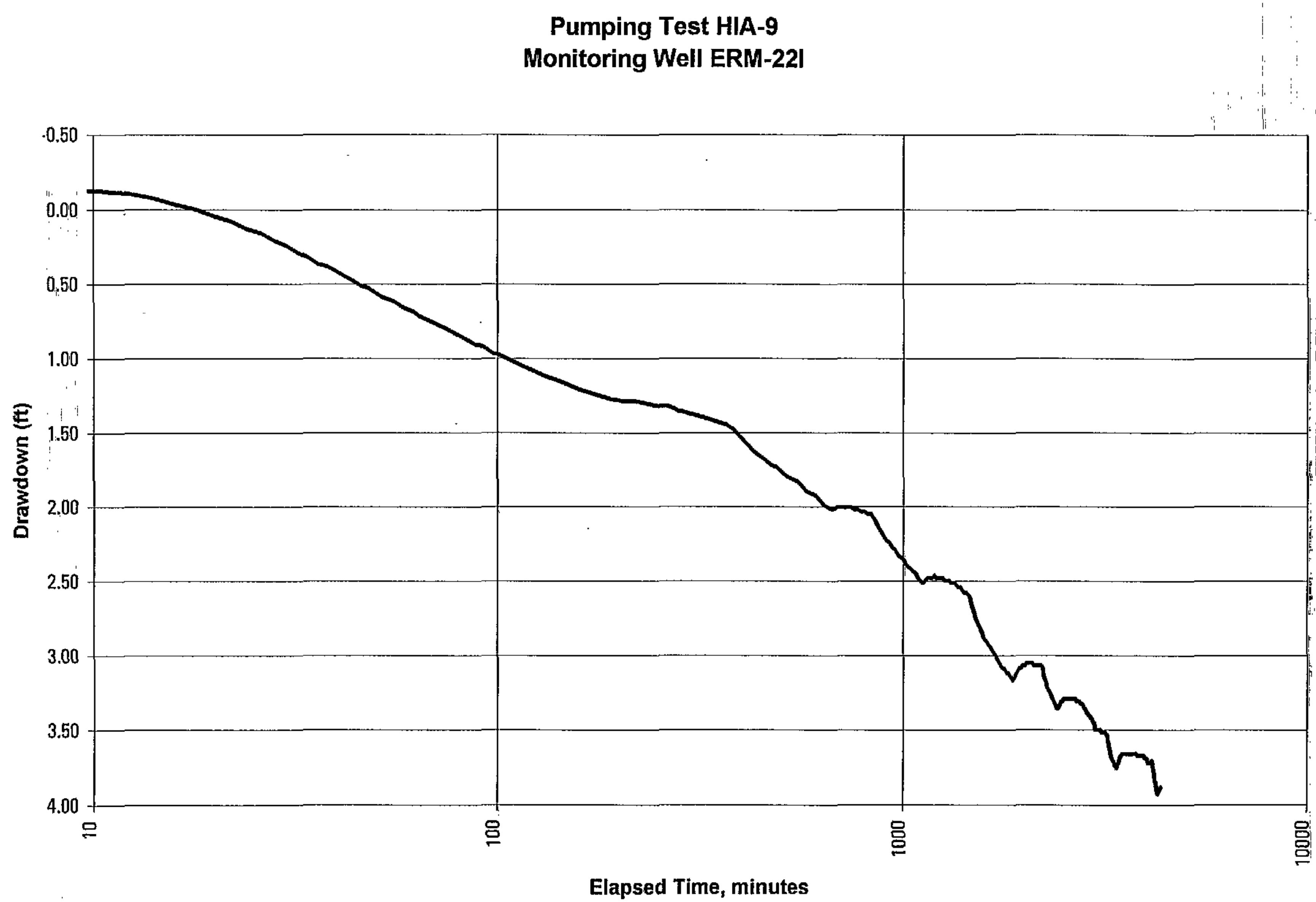


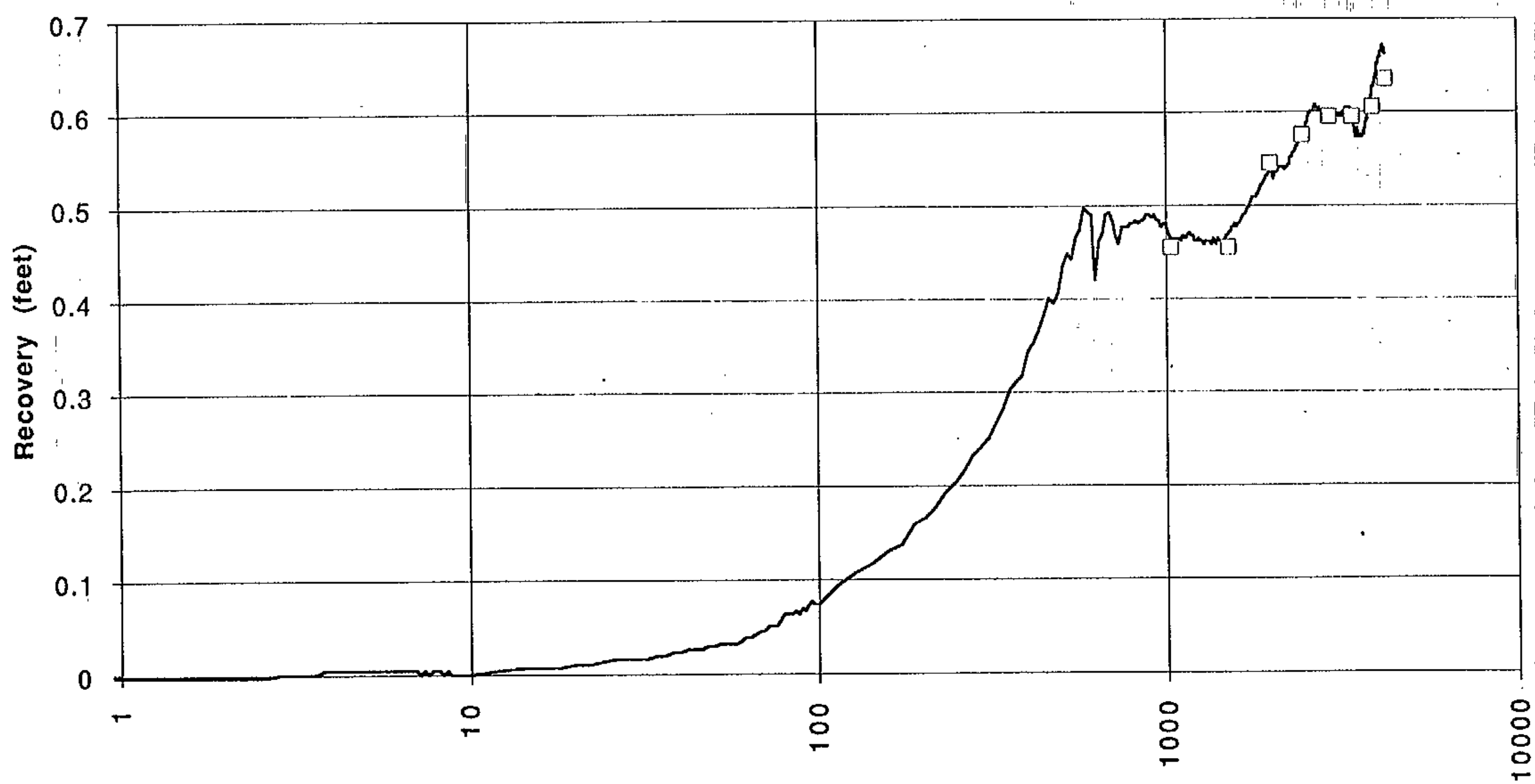
THE ERM GROUP


Pumping Test HIA-9
Observation Well ERM-21D
Drawdown (ft)
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
10
100
1000
10000
Elapsed Time, minutes


Pumping Test HIA-9
Monitoring Well ERM-22I
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Drawdown (ft)
10
100
1000
10000
Elapsed Time, minutes

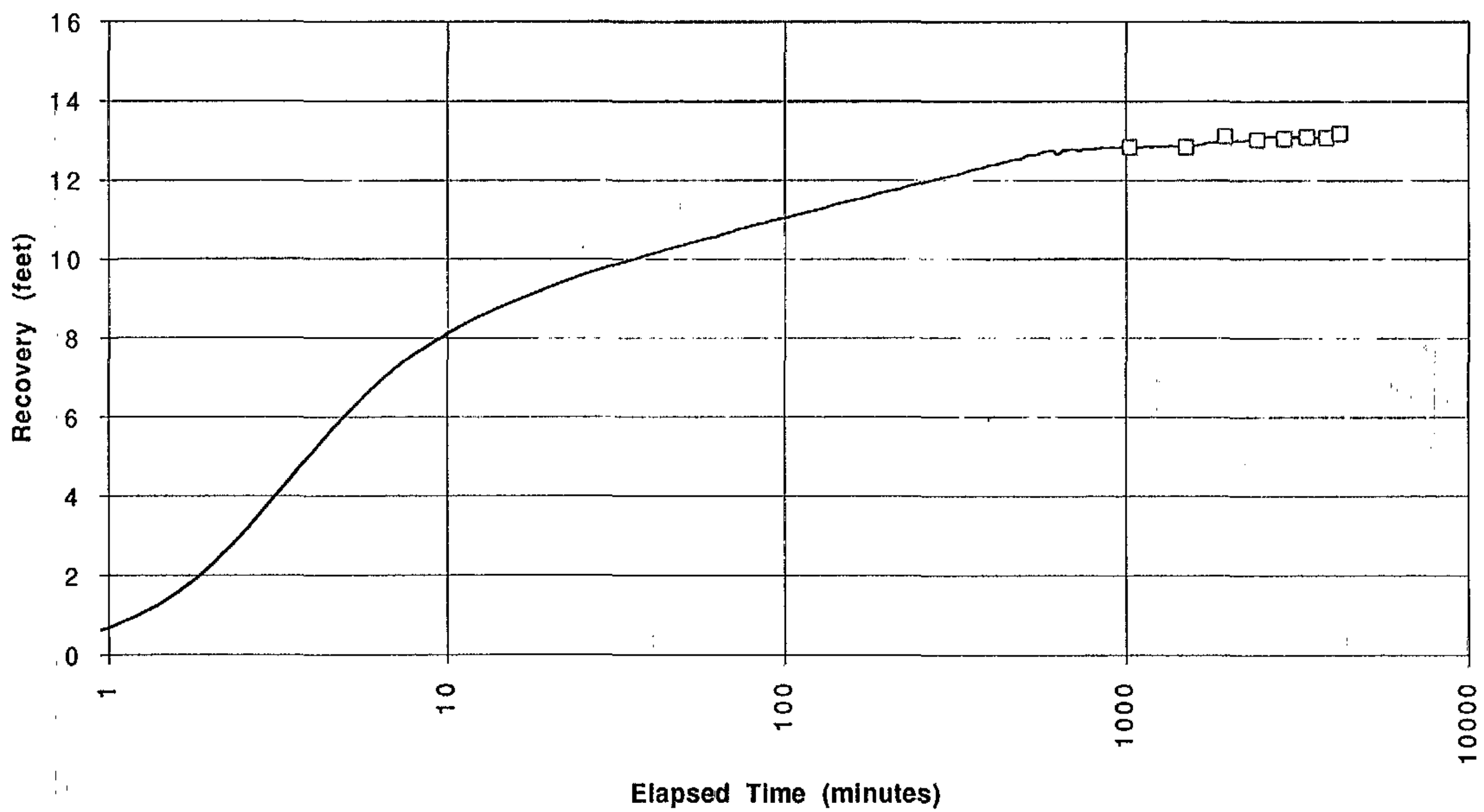
Semi-log Plots-Recovery Test HIA-13

Recovery Test HIA-13
Observation Well ERM-23S
Data Logger Measurements



Filename: [23I-Barom.]Log RCV-23I
Date Printed: 4/9/96

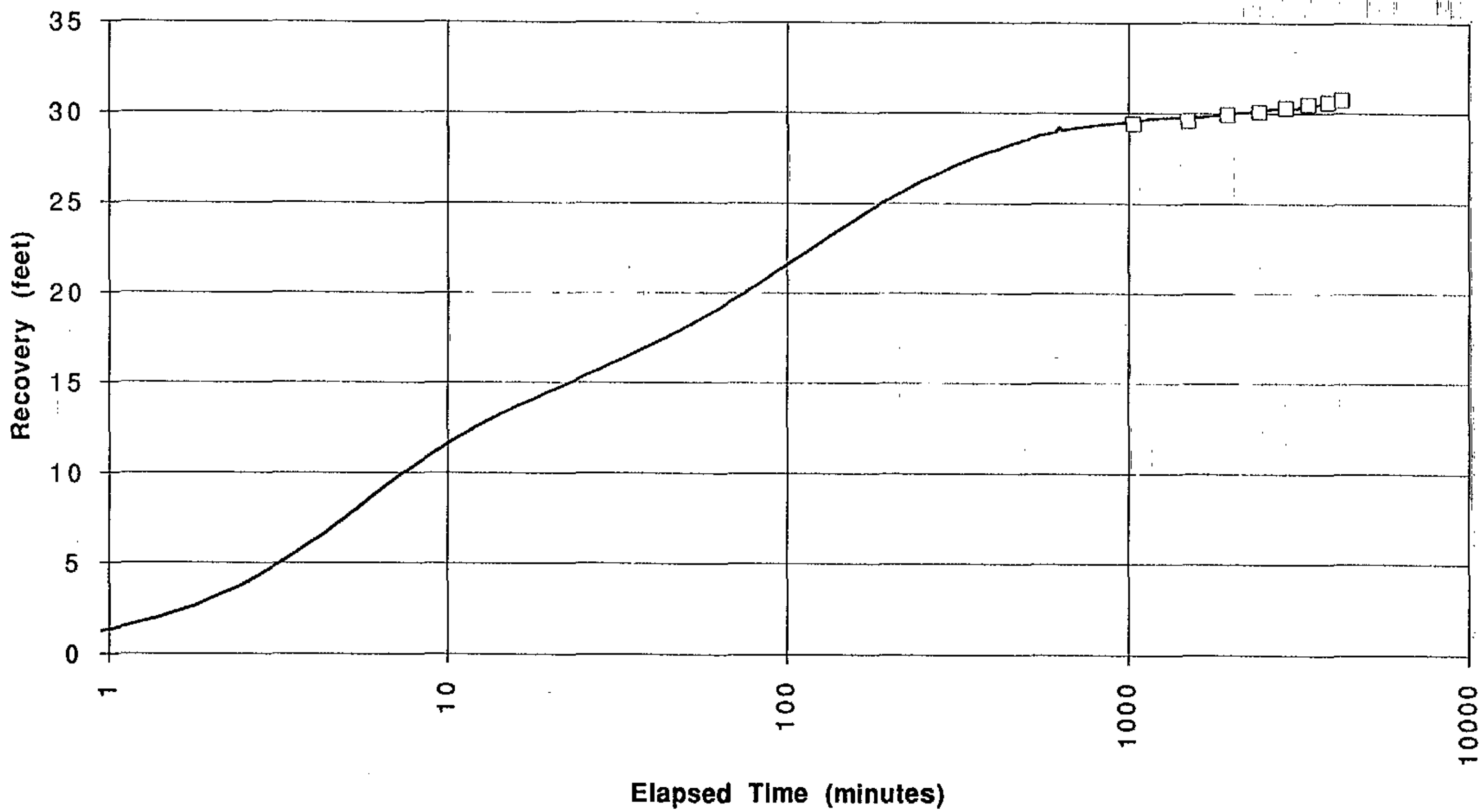
Recovery Test HIA-13
Observation Well ERM-23I
Data Logger Measurements



THE ERM GROUP

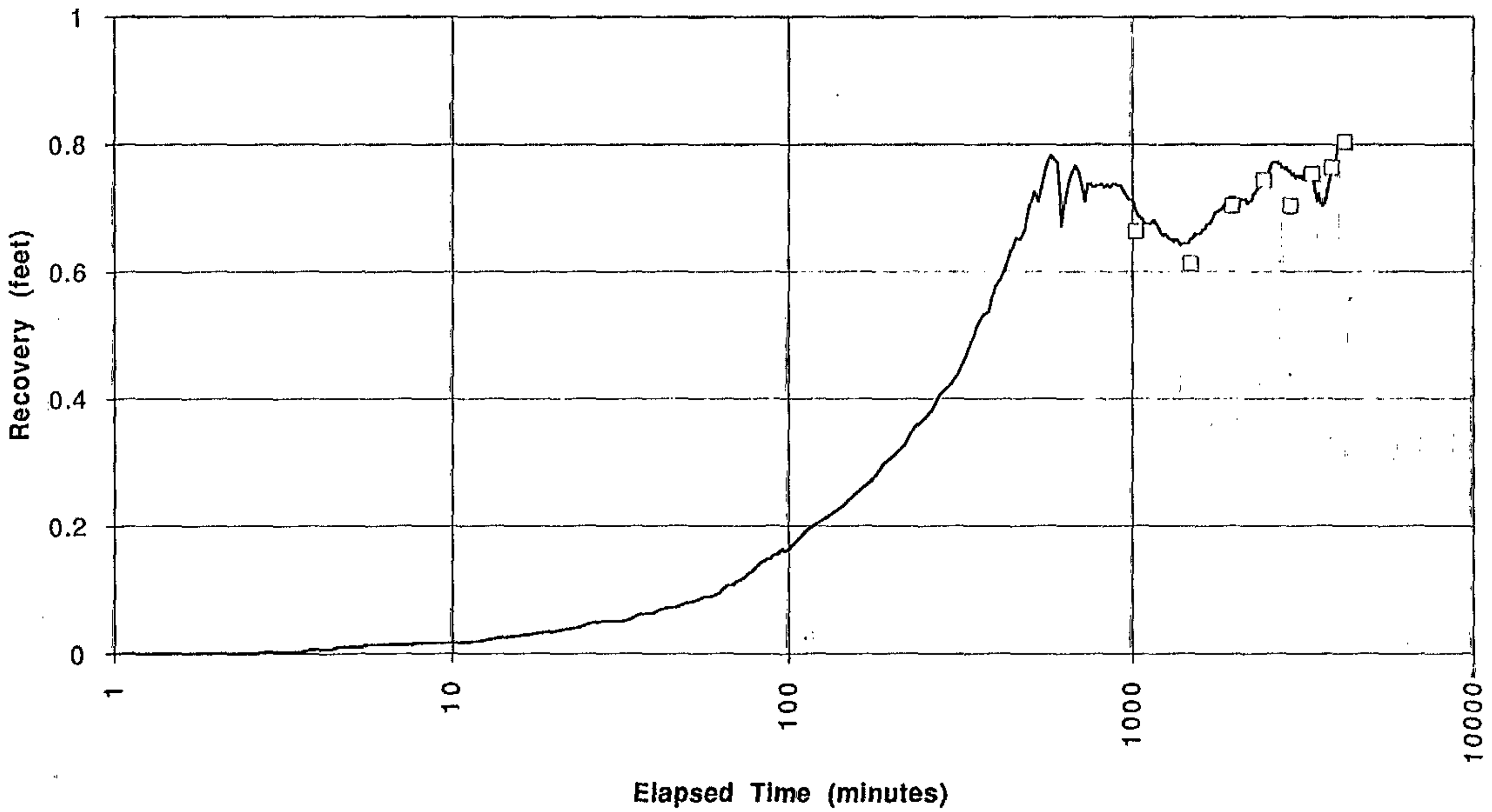
Filename : [23S-23D]Lo[illegible]V-23D
Date Printed: 4/9/96

Recovery Test HIA-13
Observation Well ERM-23D
Data Logger Measurements



THE ERM GROUP

Recovery Test HIA-13
Observation Well ERM-24S
Data Logger Measurements



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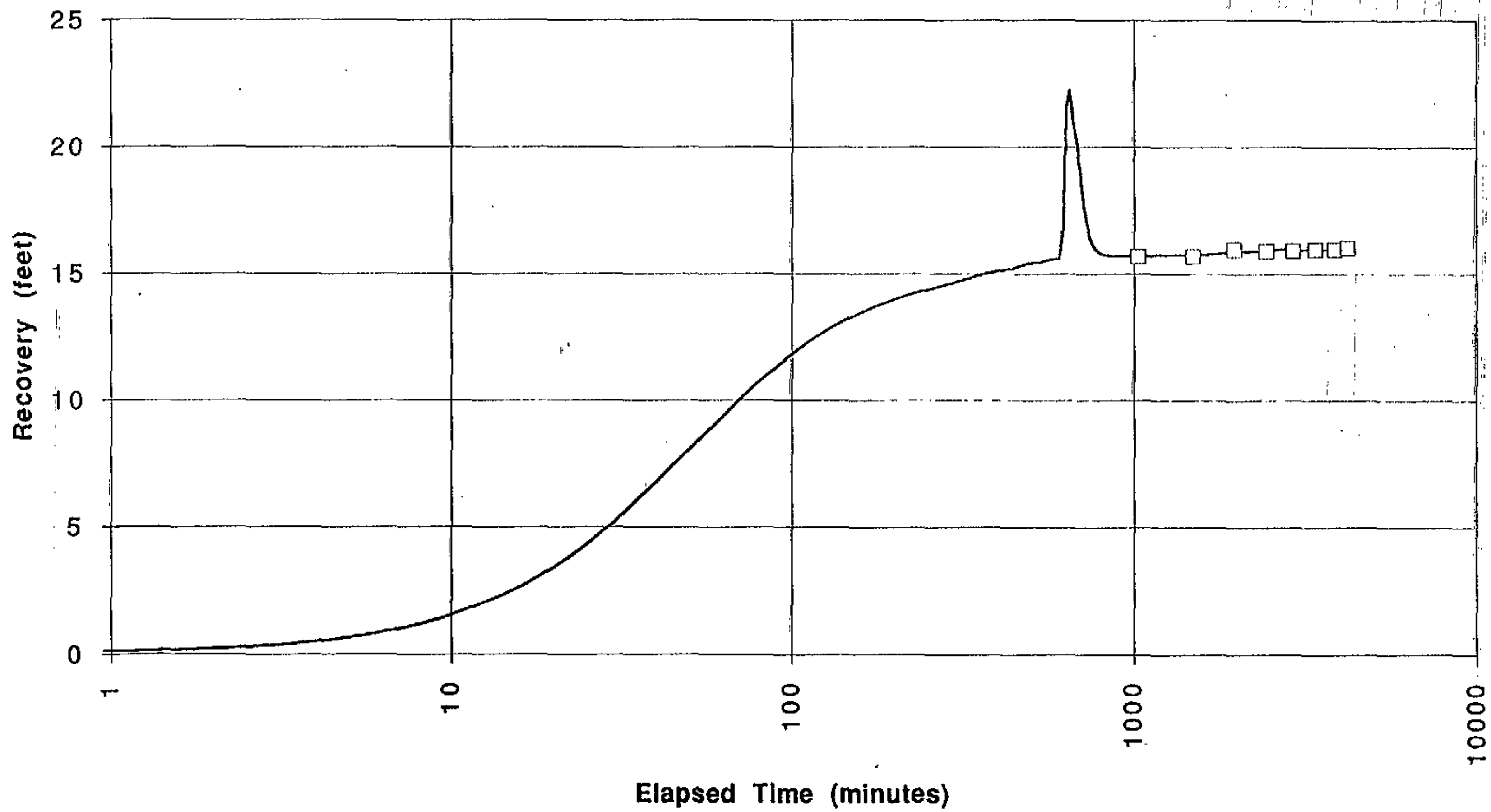
Date Printed: 4/9/96

Recovery Test HIA-13
Observation Well ERM-24I
Data Logger Measurements



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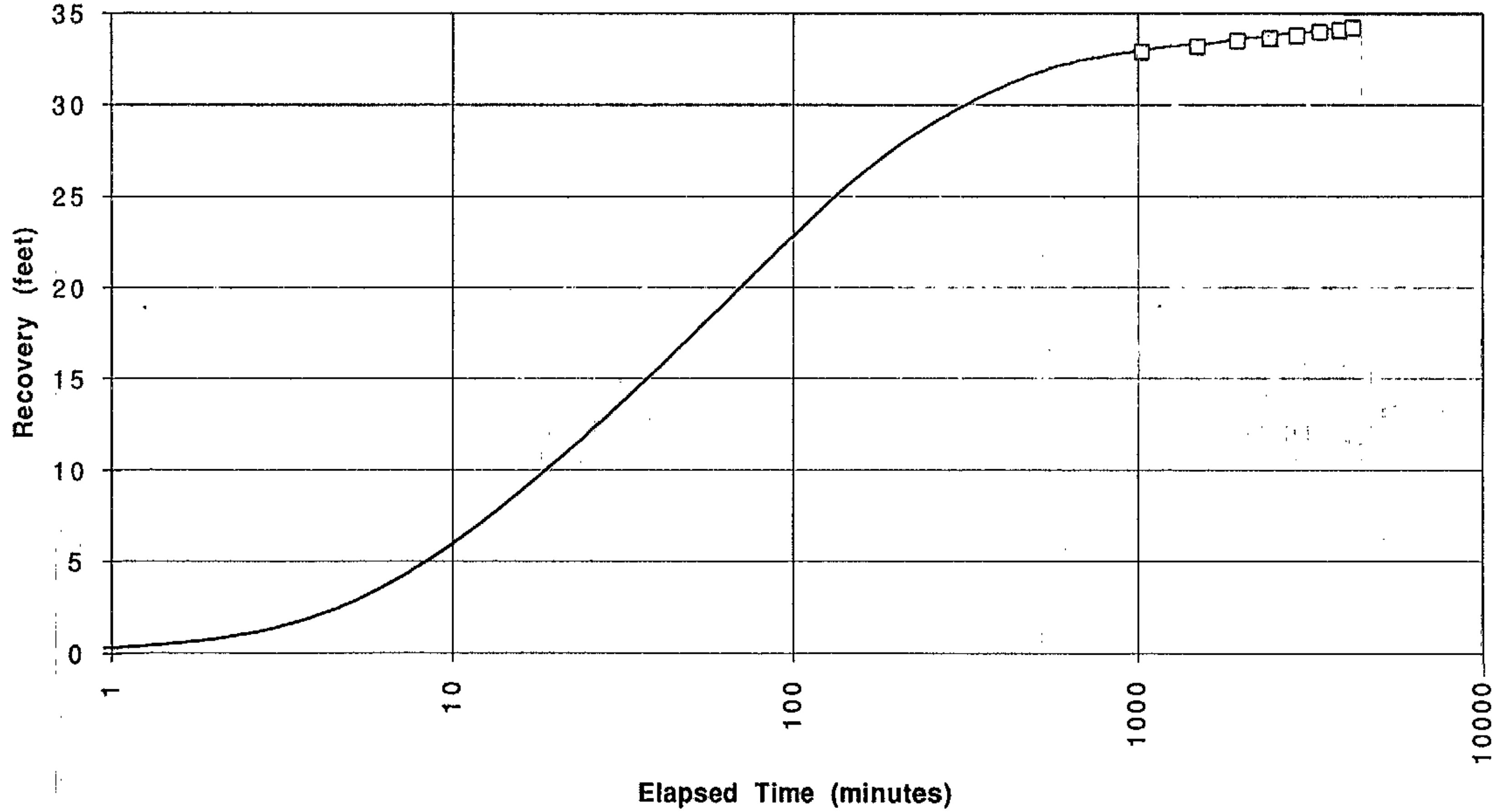
Recovery Test HIA-13
Observation Well ERM-24D
Data Logger Measurements



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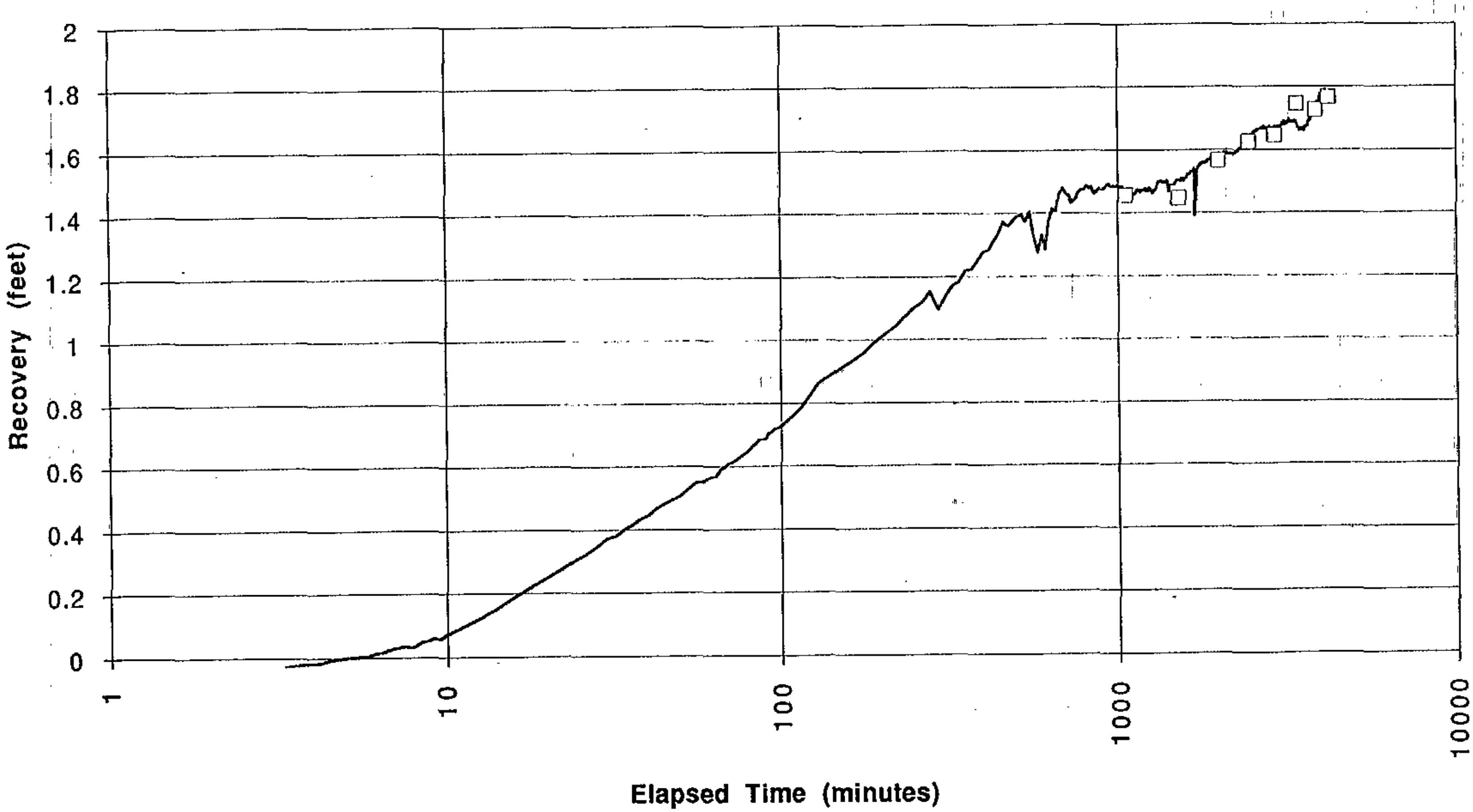
Date Printed: 4/9/96

Recovery Test HIA-13
Observation Well ERM-32I
Data Logger Measurements



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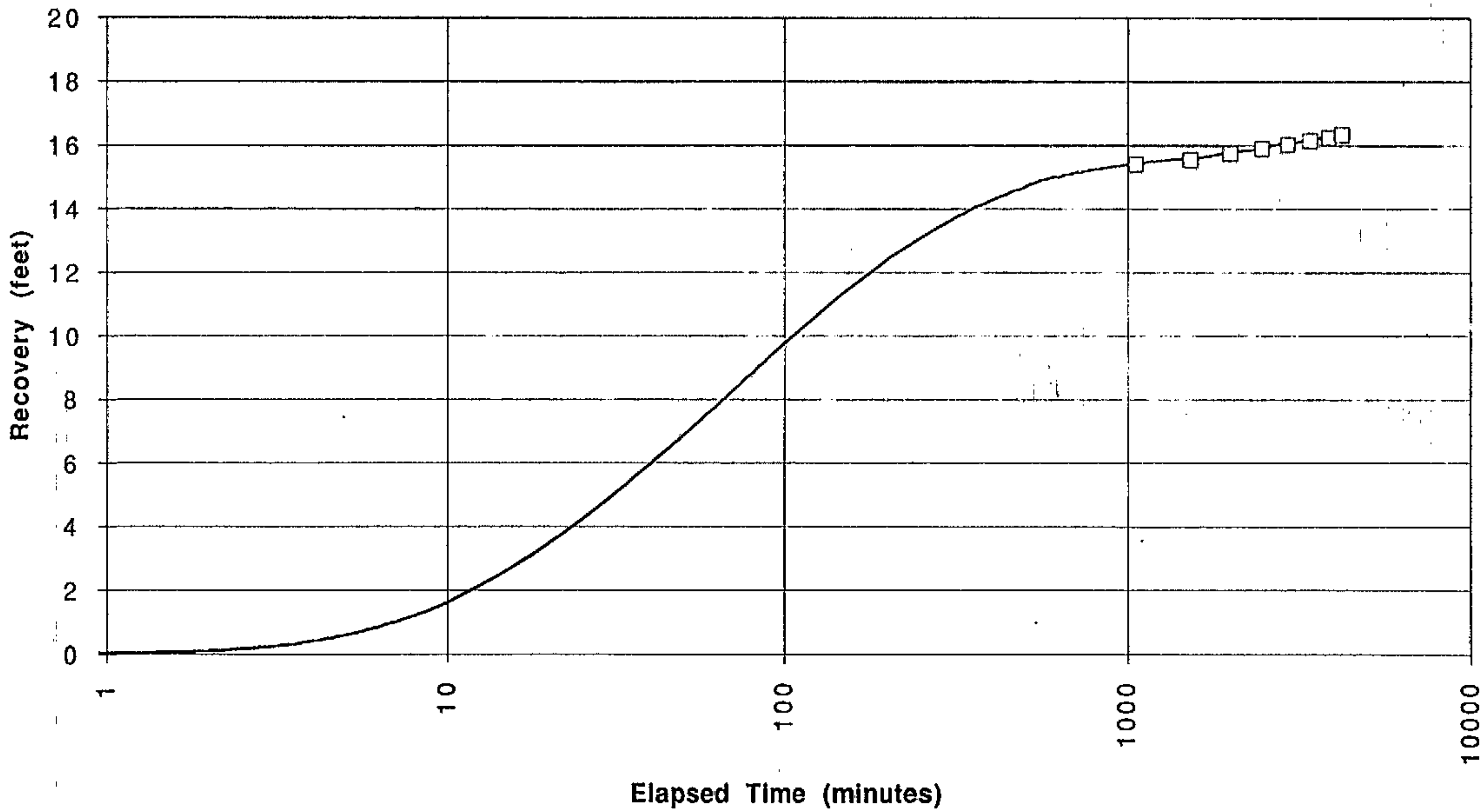
Recovery Test HIA-13
Observation Well ERM-32D
Data Logger Measurements



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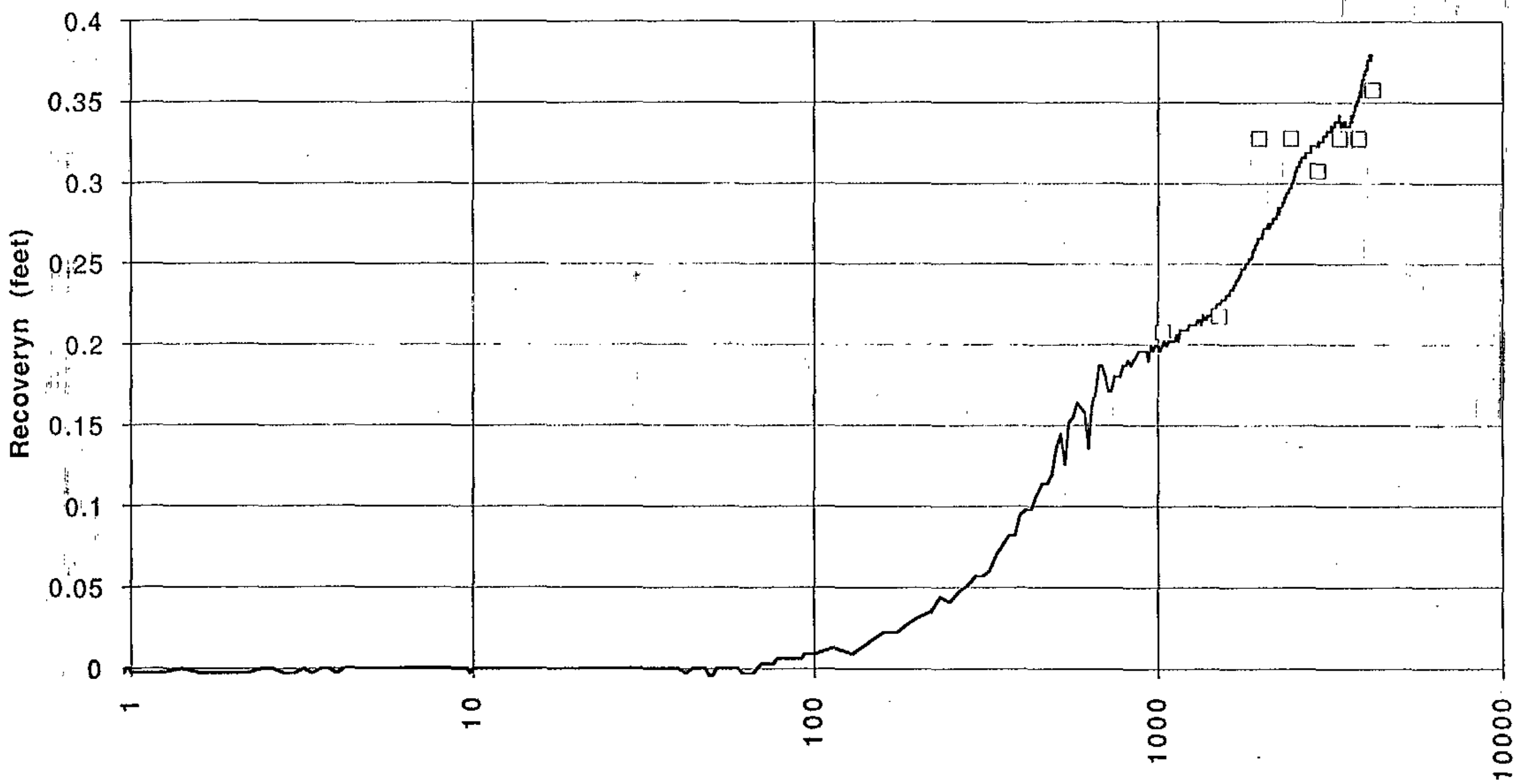
Date Printed: 4/9/96

Recovery Test HIA-13
Observation Well RFW-3
Data Logger Measurements



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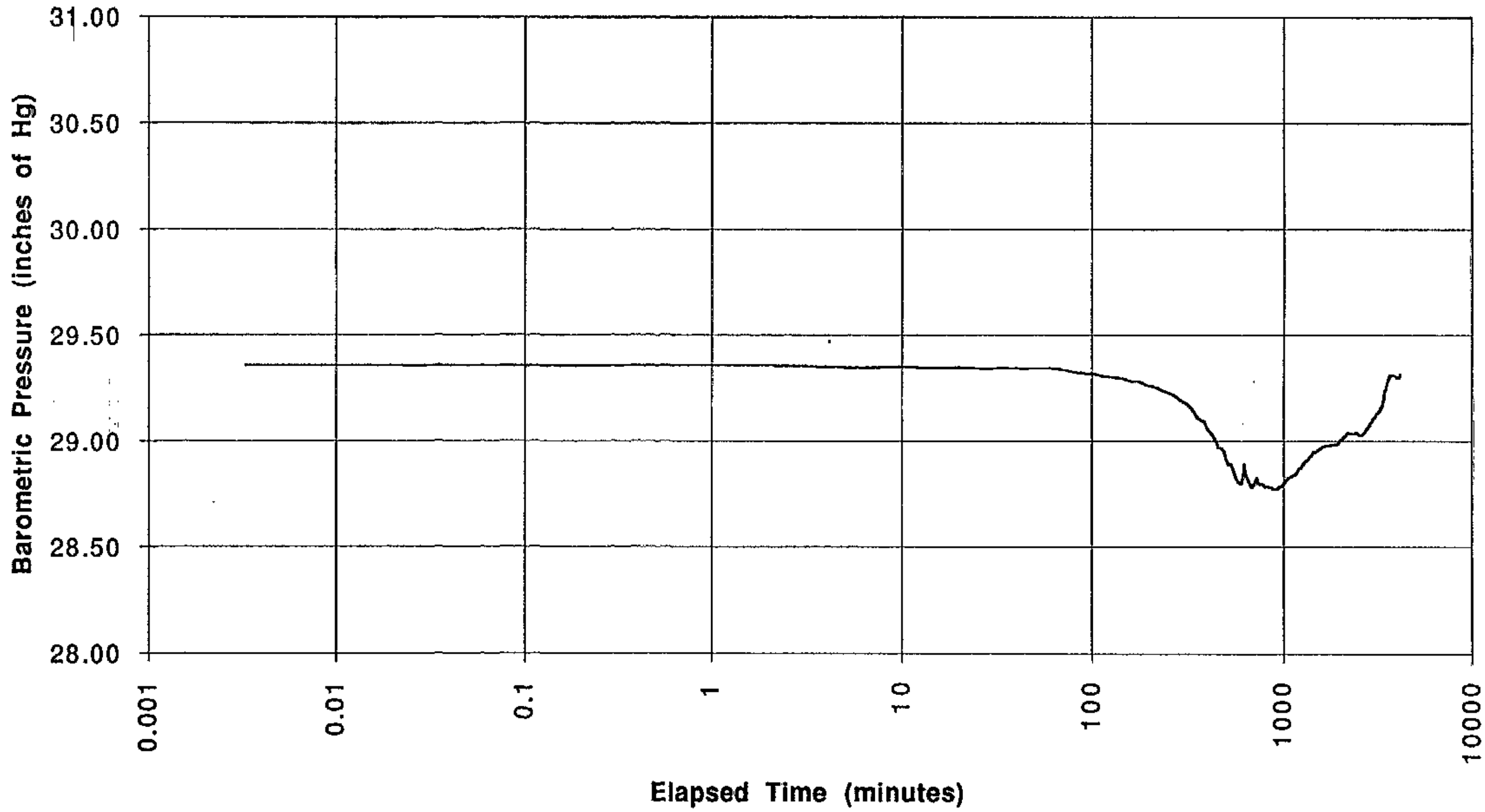
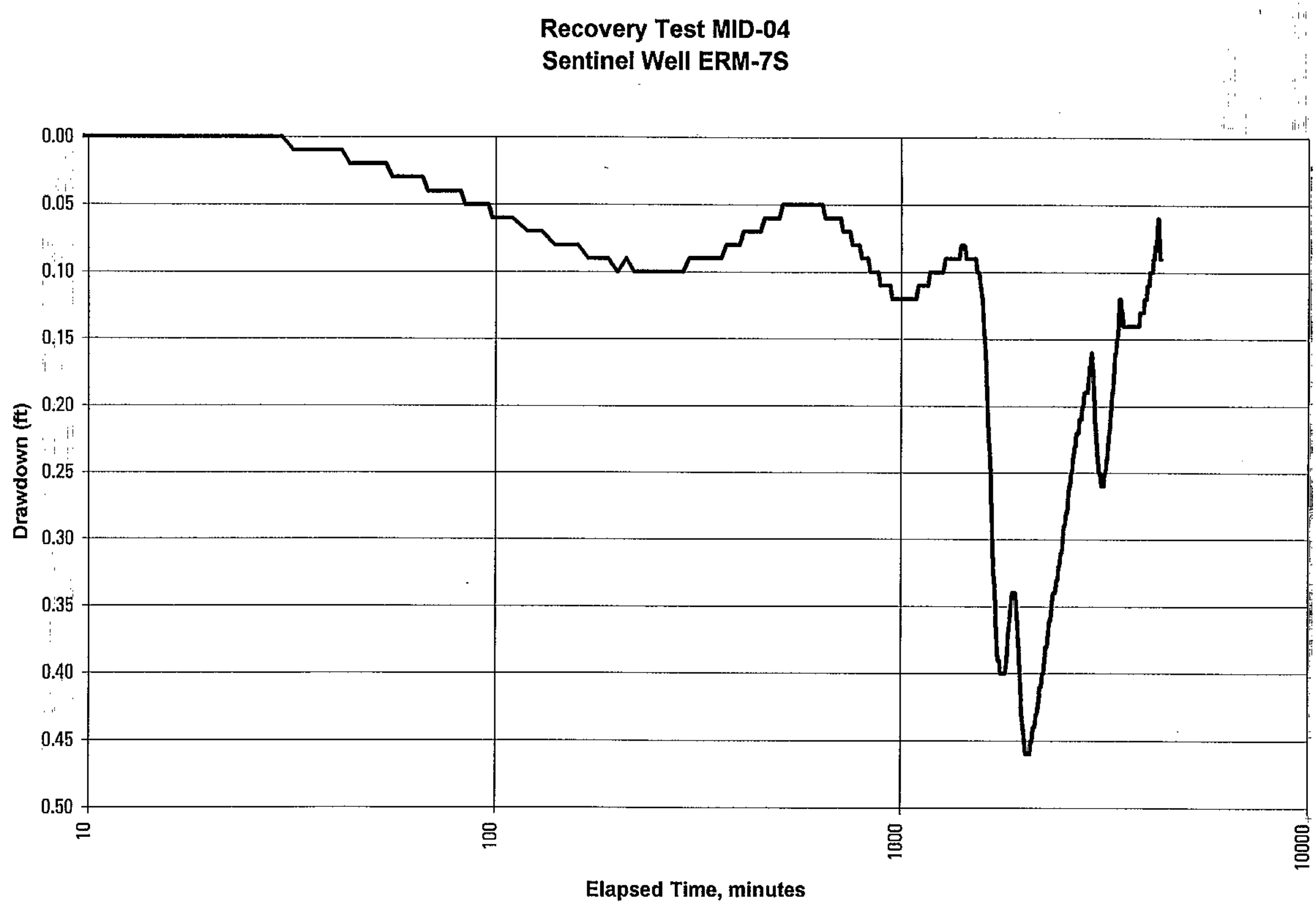
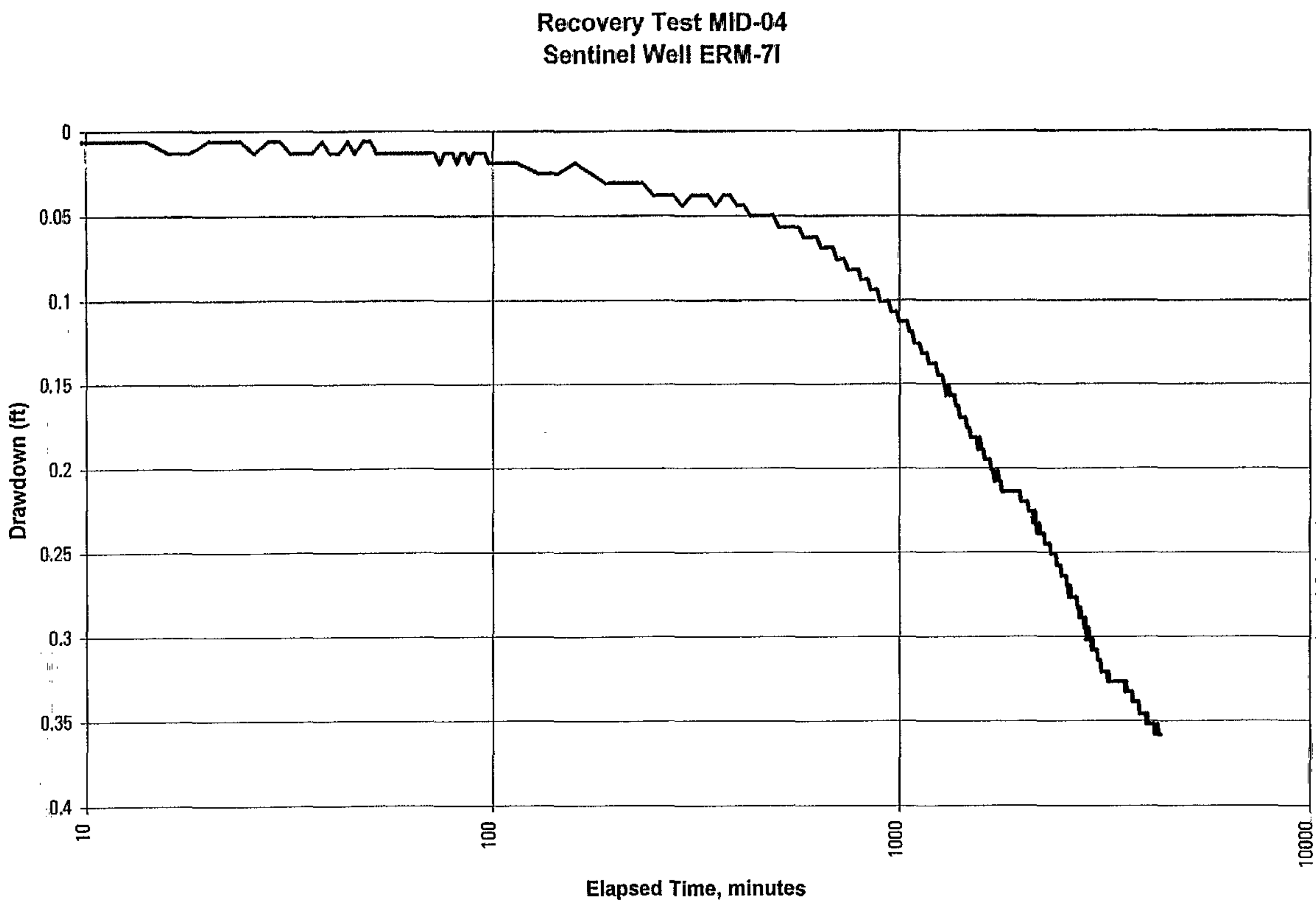
Recovery Test HIA-13
Barometric Pressure
Data Logger Measurements



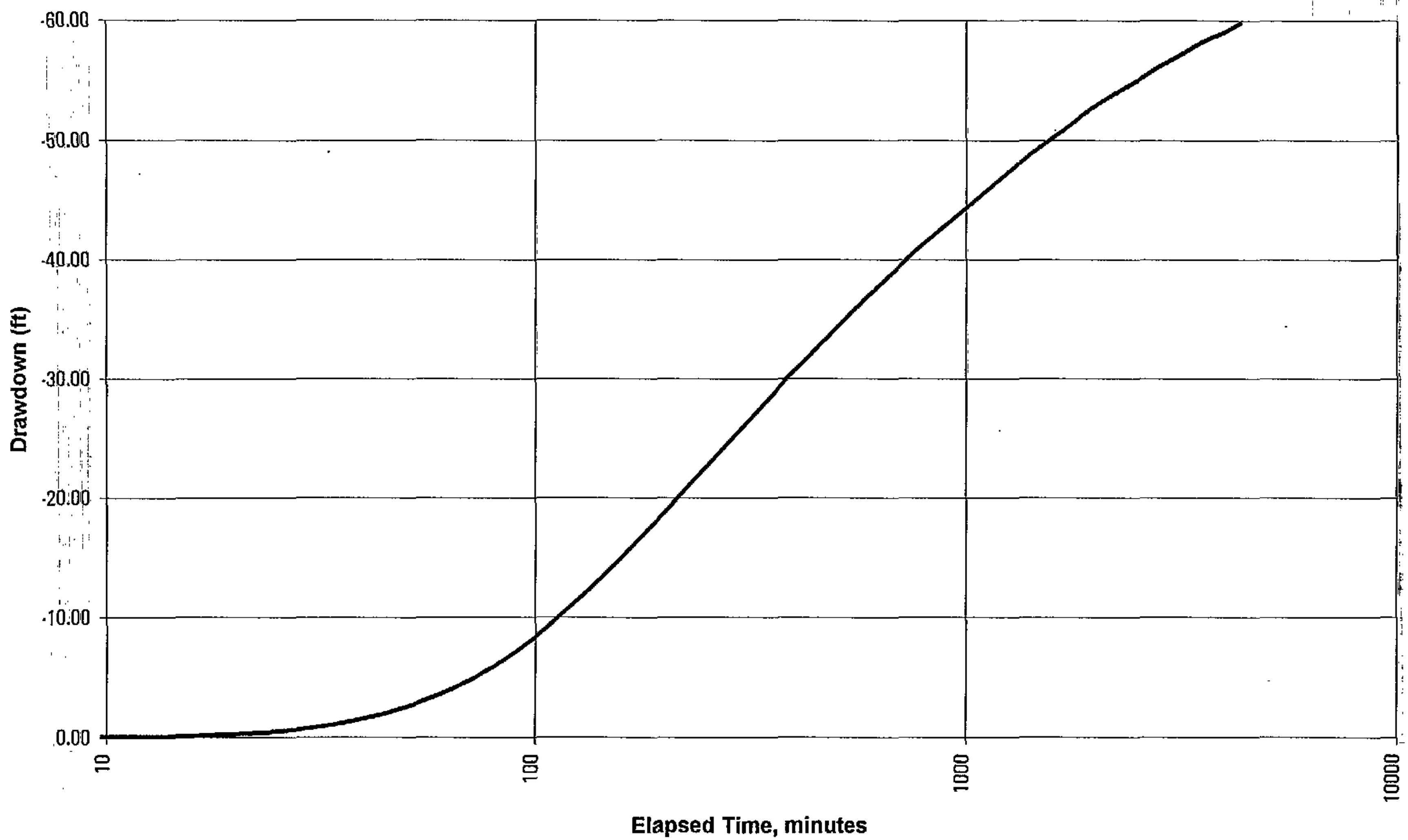
Drawdown vs. Log Time-Recovery Test MID-04


Recovery Test MID-04
Sentinel Well ERM-7S
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Drawdown (ft)
10
100
1000
10000
Elapsed Time, minutes


Recovery Test MID-04
Sentinel Well ERM-7I
Drawdown (ft)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
10
100
1000
10000
Elapsed Time, minutes

Filename: ...REV-7D.XLW
Date Printed: 12/20/95

Recovery Test MID-04
Sentinel Well ERM-7D



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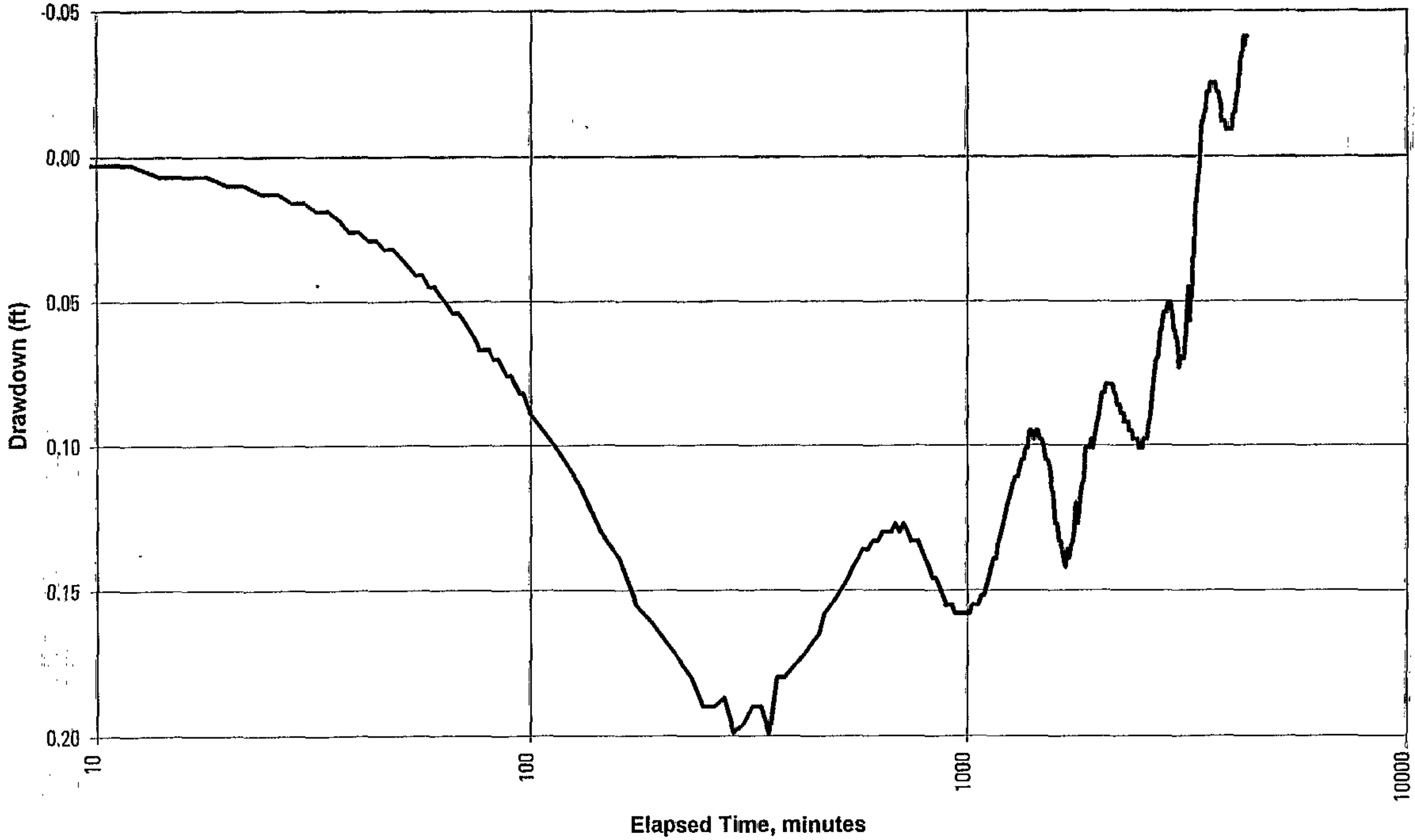
Filename: MID4-8SB.XLW
Date Printed: 12/20/95

Recovery Test MID-04
Sentinel Well ERM-8S



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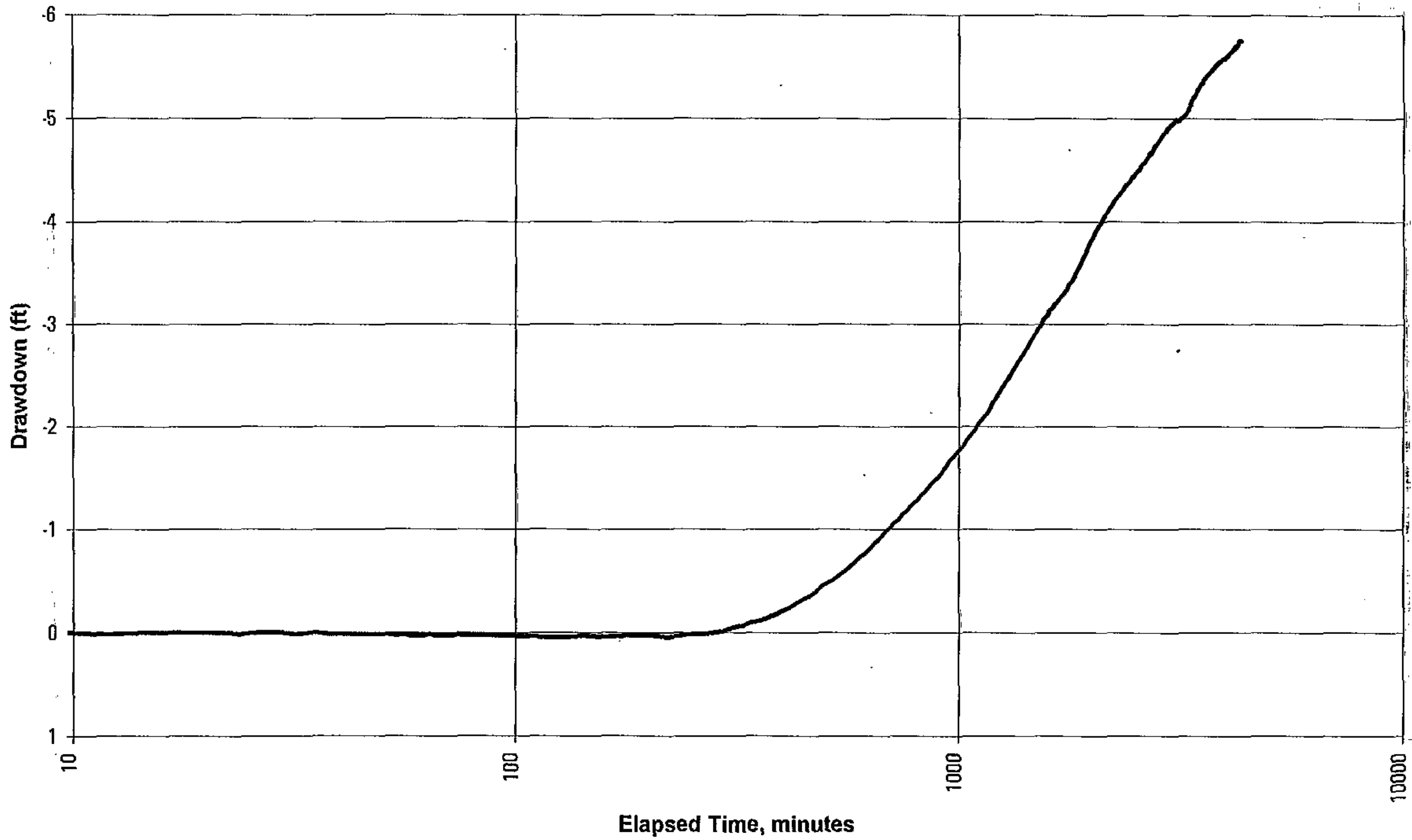
Date Printed: 12/20/95

Recovery Test MID-04
Sentinel Well ERM-8I



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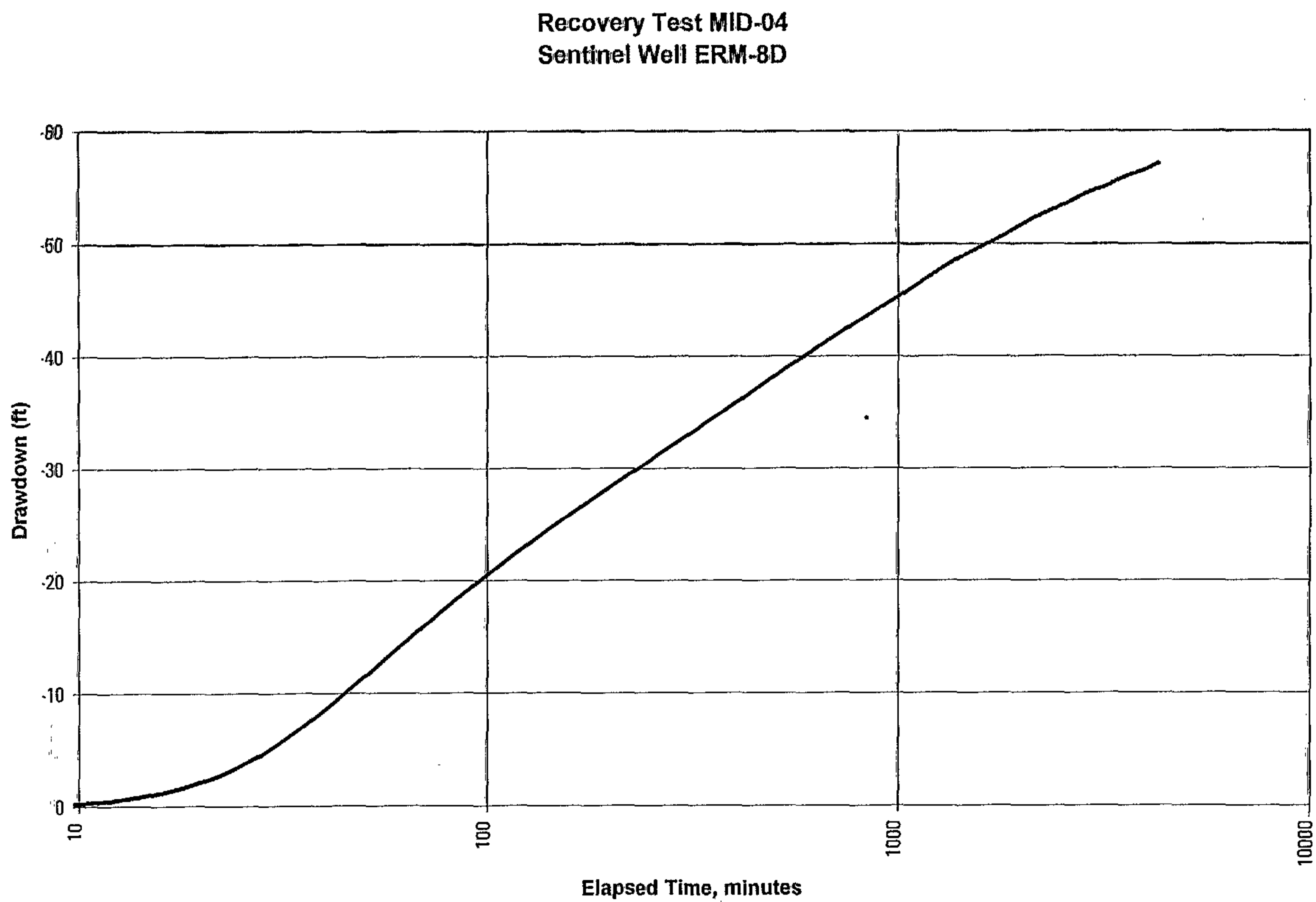
Date Printed: 12/20/95



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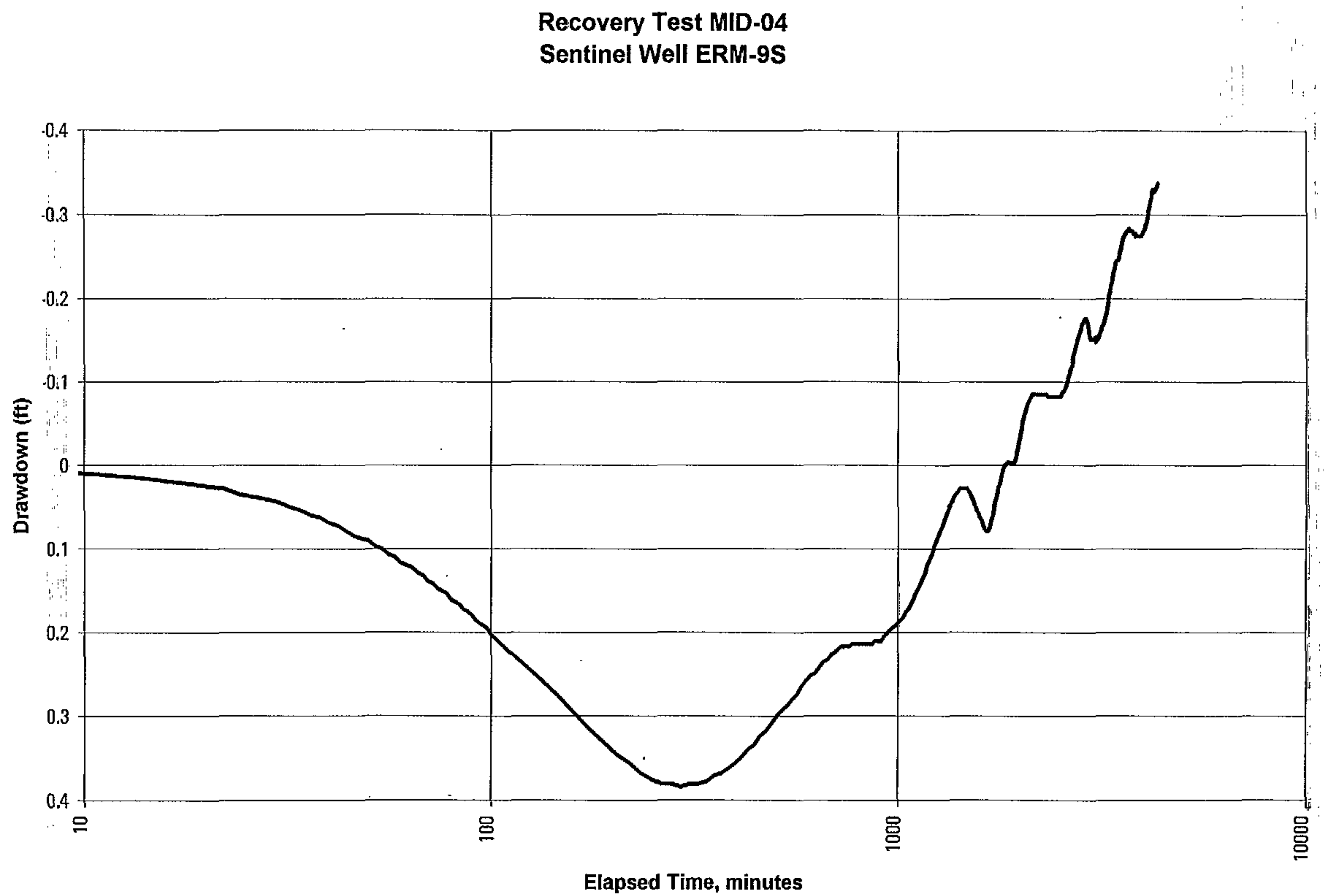

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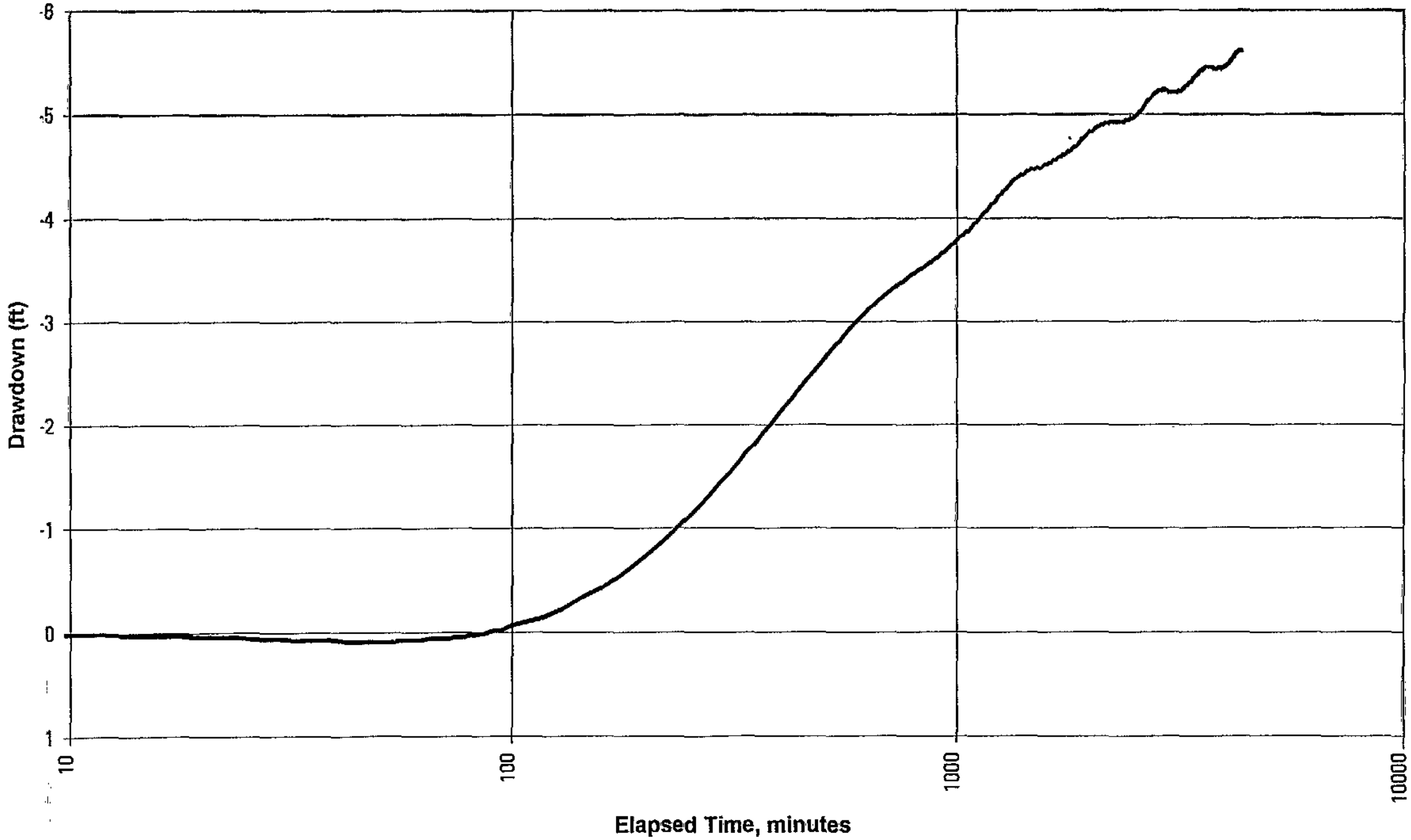
Filename: REV 9ID.XLW
Date Printed: 12/20/95

Recovery Test MID-04
Sentinel Well ERM-9I



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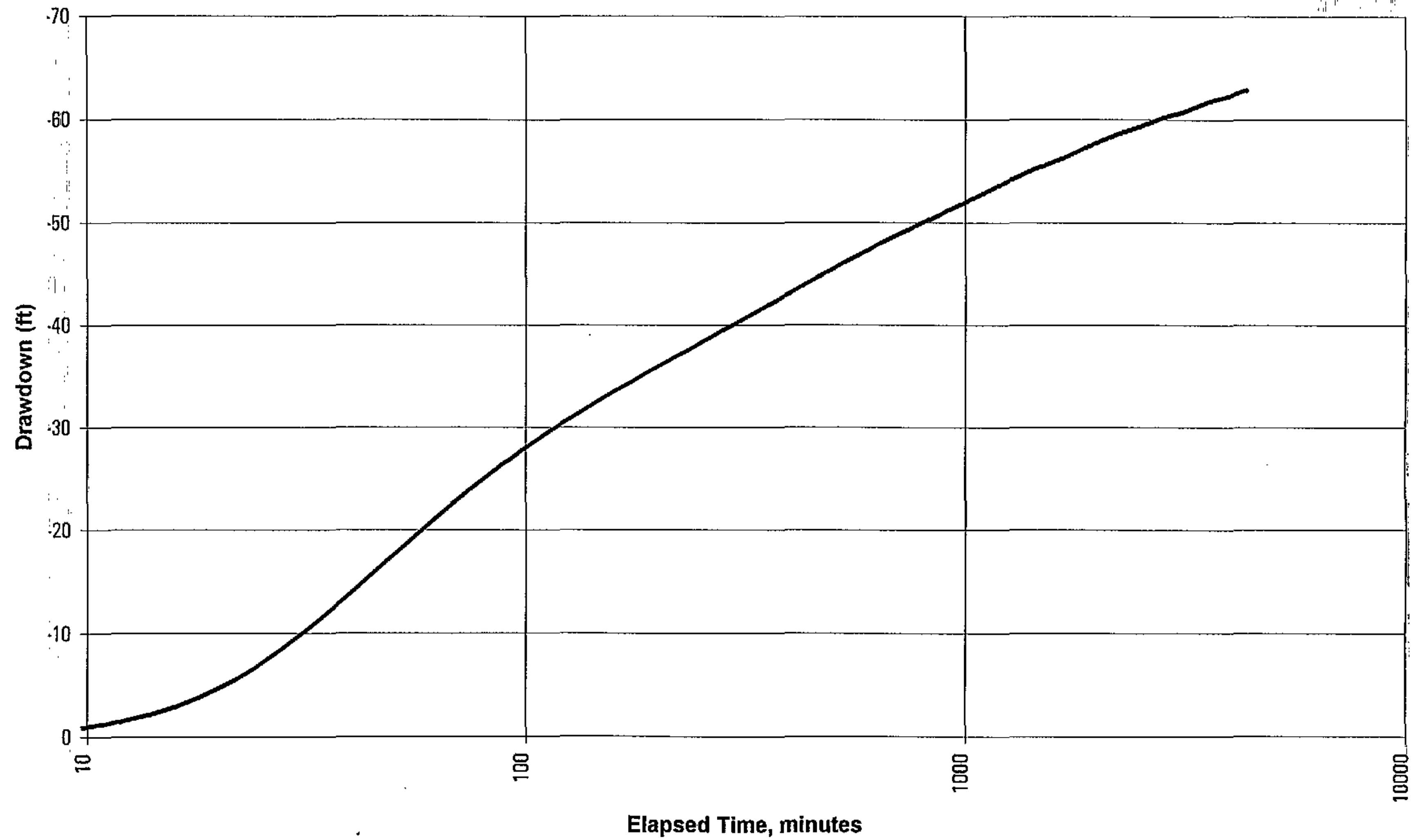
Date Printed: 12/20/95

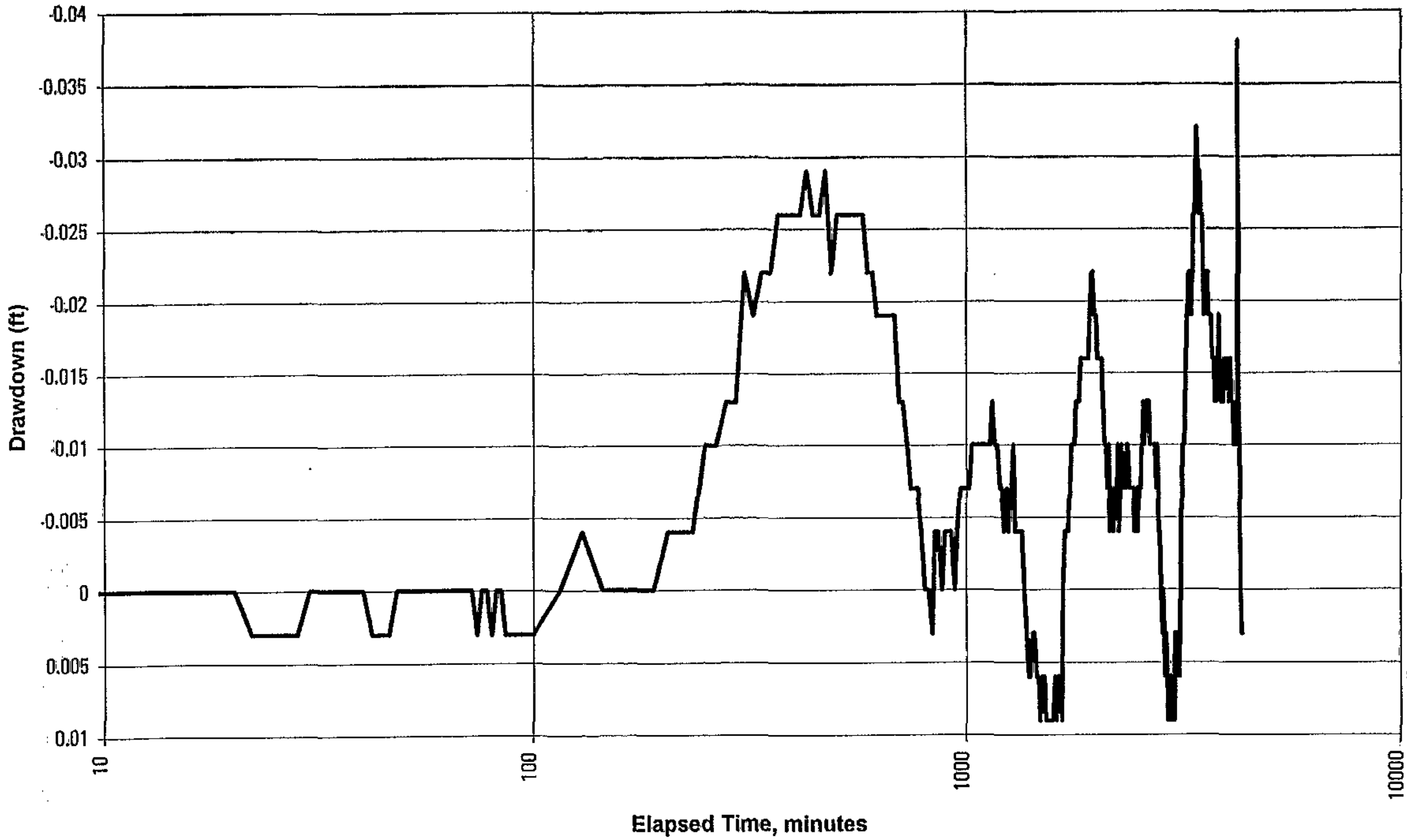
Recovery Test MID-04
Sentinel Well ERM-9D



THE ERM GROUP

Filename: MID413S.XLW
Date Printed: 12/20/95

Recovery Test MID-04
Monitoring Well ERM-13S



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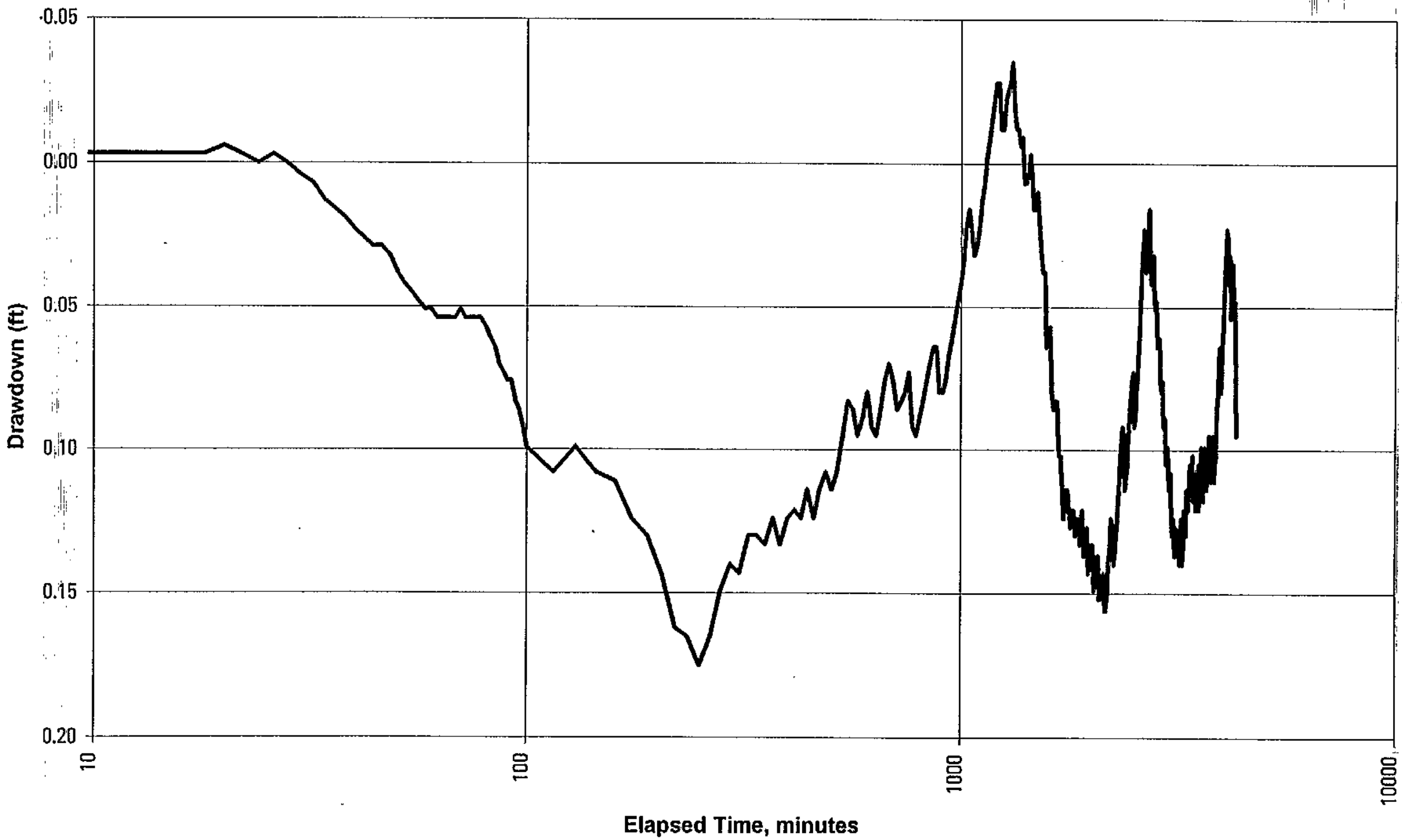
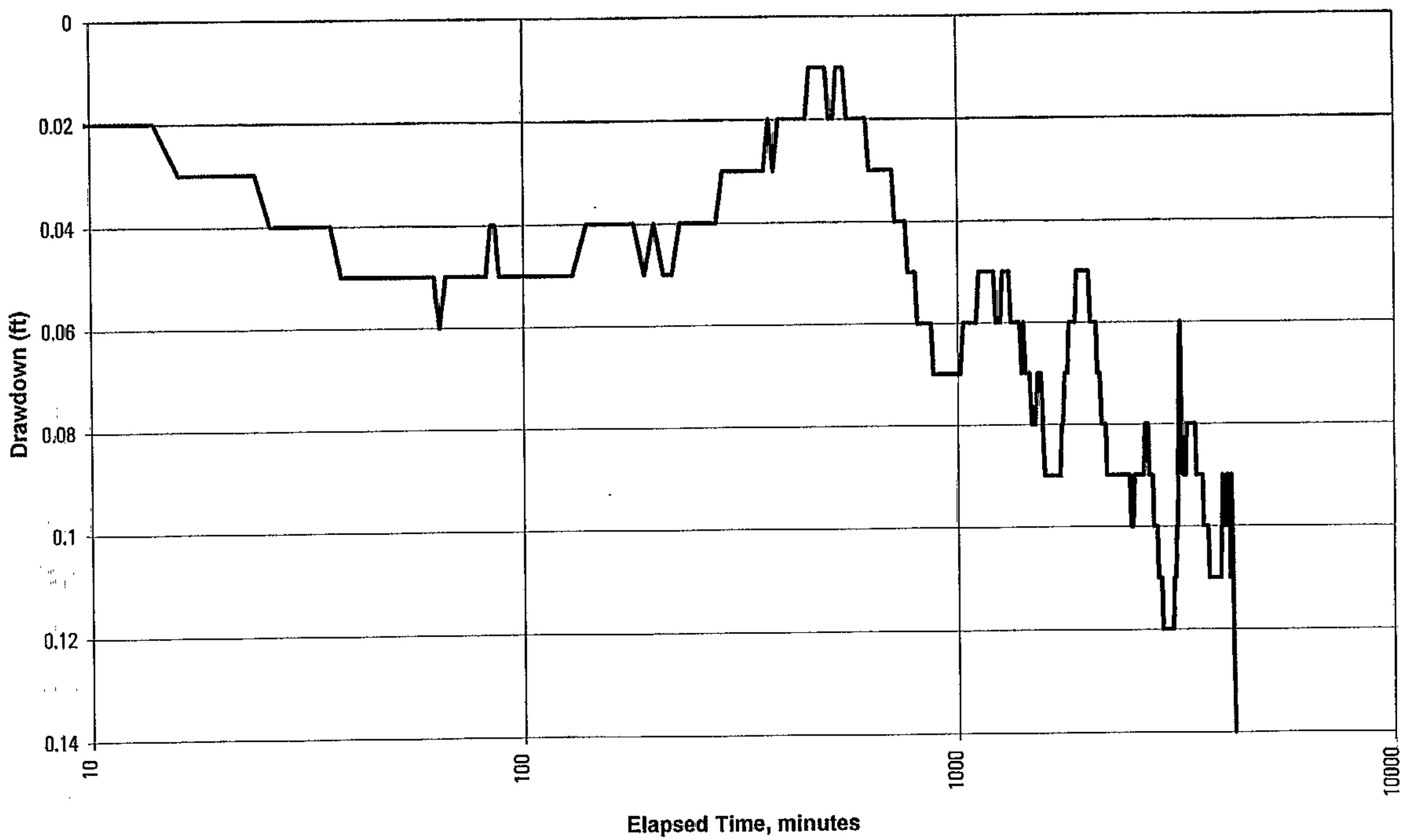
Filenam D413IS.XLW
Date Printed: 12/20/95

Recovery Test MID-04
Monitoring Well ERM-13I



THE ERM GROUP

Recovery Test MID-04
Monitoring Well ERM-14S



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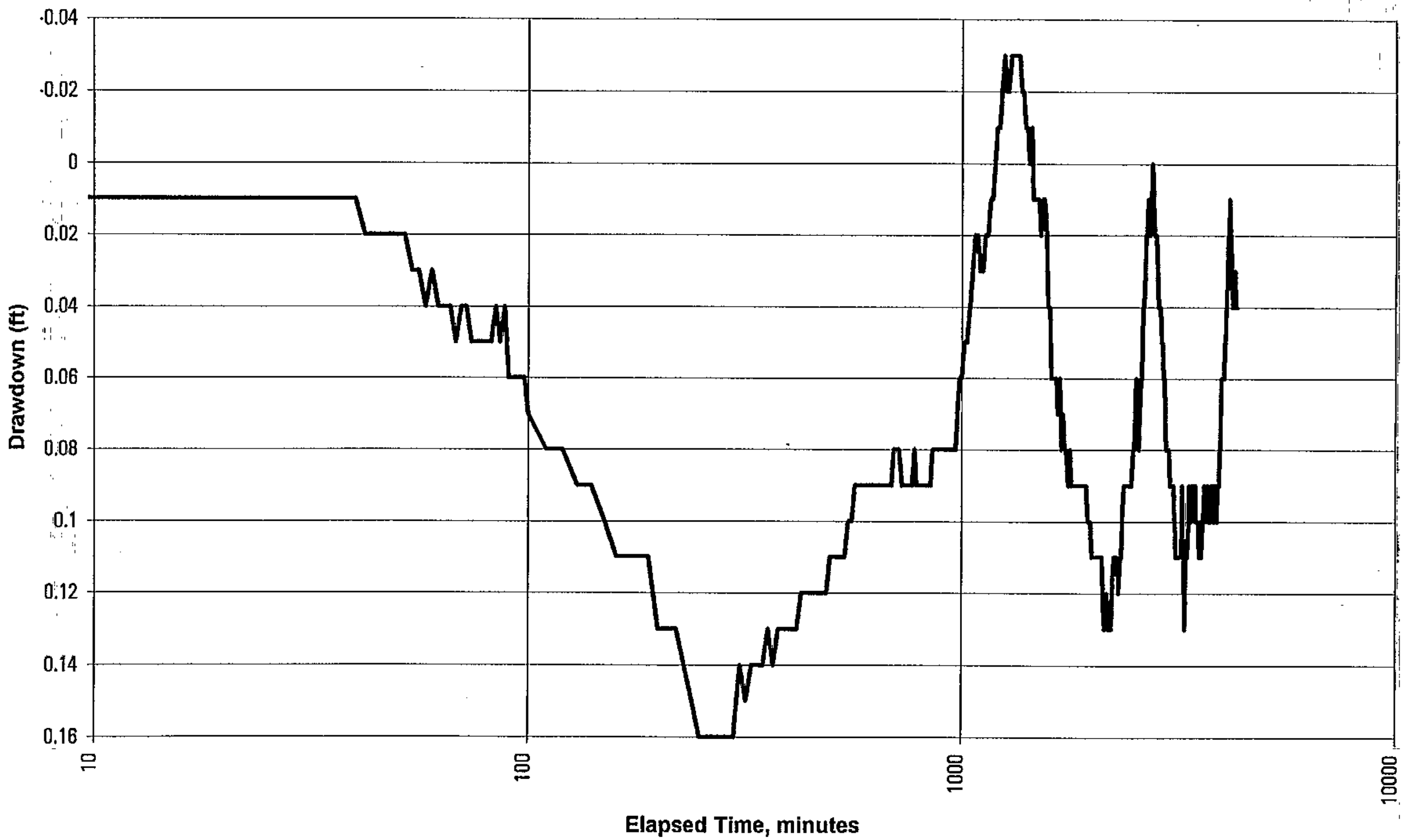
Date Printed: 12/20/95

Recovery Test MID-04
Monitoring Well ERM-14I



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Appendix L
Ground Water Flow Modeling

DRAFT REPORT

Middletown Airfield NPL Site
Middletown, Pennsylvania

Ground Water Flow Modeling

1 July 1996

ERM Program Management Company
855 Springdale Drive
Exton, Pennsylvania 19341

ERM®

TABLE OF CONTENTS

LIST OF TABLES *FOLLOWING PAGE*

LIST OF FIGURES

L.0 *GROUND WATER FLOW MODELING*

L.1 *INTRODUCTION*

The Ground Water Flow Modeling was a part of the Supplemental Studies Investigation (SSI) conducted at the Middletown Airfield NPL Site, Pennsylvania. In accordance with the April 1992 Explanation of Significant Differences (ESD), the SSI at the Middletown Airfield NPL Site, Pennsylvania was to include:

- an assessment of the impact of contaminated soils on ground water based on vadose leaching modeling, and
- evaluation of the future timing, location, and rates of contaminant movement based on ground water flow and transport modeling.

Comparison of constituent concentrations in soil samples against screening criteria specified by the Environmental Protection Agency (EPA) and the Pennsylvania Department of Environmental Protection (PADEP) did not identify specific source areas that would impact ground water. Since no contaminant source areas were defined, vadose zone modeling and contaminant transport modeling were not warranted. However, 3-dimensional ground water flow modeling was performed to evaluate several pumping scenarios and determine the reconfiguration of the Harrisburg International Airport (HIA) production well rates. This work was conducted under Contract Number DACW 45-93-D-0017, Delivery Order Number 009.

L.2 *MODELING OBJECTIVES*

The objectives of the ground water flow modeling were to:

- develop a 3-dimensional model to simulate ground water flow in the area of the HIA and the North Base Landfill;
- to determine if the current HIA pumping configuration was effectively capturing the impacted ground water beneath the airport; and
- evaluate alternative HIA pumping scenarios to contain the impacted ground water.

Previous studies and recent site information were taken into consideration. The modeling results were evaluated to provide a recommendation of how to reconfigure the current HIA well operating scheme to maximize plume containment, or a justification describing why reconfiguration is not necessary.

L.3 *SCOPE OF WORK*

Numerical modeling was used to evaluate reconfiguration of the HIA production wells, considering only ground water flow and the present contaminant plume location. The modeling approach consisted of several tasks:

- Review and evaluation of existing hydrogeologic data;
- Develop a conceptual model of the site ground water flow regime;
- Ground Water Flow Modeling, including:
  - creation of a 3-dimensional numerical flow model to evaluate ground water flow patterns,
  - calibration and validation of the flow model;
  - simulations of HIA production wells;
  - simulation of the alternative reconfiguration of HIA production wells; and
- Reporting.

L.4 MODEL SELECTION

ERM applied the USGS's Three Dimensional Modular Ground Water Flow Model (MODFLOW) developed by McDonald and Harbaugh (1988). MODFLOW is a well documented, tested, and accepted program. The execution of numerical modeling efforts is enhanced through the use of Ground water Modeling System (GMS), a pre- and post-processor, developed by the Department of Defense in conjunction with Brigham Young University. The 3-D numerical ground water flow model expanded on the 2-D analytical element modeling performed during the capture zone analysis.

L.5 *REVIEW AND EVALUATION OF EXISTING DATA*

The hydrogeologic data collected to date was incorporated into an evaluation of the site hydrogeology. The boundary conditions and aquifer parameters determined from the capture zone tests and analysis, performed as part of the SSI, were incorporated into the development of the numerical model. The results of the capture zone tests and analysis are detailed in Appendix K.

A ground water contour map developed from the water level measurements collected in May 1995, prior to the site-wide sampling event, was used to represent current conditions (Appendix C, Plate 8).

L.5.1 *Geology*

The Site and the surrounding area are underlain by a complex sequence of interbedded sedimentary rocks known as the Gettysburg Formation of the Triassic Age Newark Group. Wood (1980) has mapped the Site and its vicinity as underlain by "red and maroon, micaceous and silty mudstones and shales, locally calcareous and some thin red siltstone to very fine sandstone interbeds." To the northeast of the Site in the Meade Heights Area and beyond, the Gettysburg Formation consists primarily of sandstone units. The strike of bedding ranges from N5°E to N65°E with an average strike of N43°E. The dip of bedding is to the northwest ranging from 19° to 38° with an average dip of 26°NW. The bedrock may be extensively fractured and jointed locally, but no faults have been mapped in the immediate vicinity of the site. Over most of the Site, the Gettysburg Formation is overlain by Quaternary Age alluvium (unconsolidated silts, sands and gravels) and by anthropogenic fill material. The bedrock is moderately to extensively weathered near its interface with the overlying alluvium and fill.

Ground water at the Site occurs under unconfined (water table) conditions within the alluvium and the weathered upper zone of the Gettysburg Formation. The water table aquifer extends to a depth of about 40 feet at the HIA and to a depth of about 20 feet in the North Base Landfill Area. The confined ground water system in the Gettysburg Formation consists of a series of stacked aquifers that generally dip 26°NW and which extend downdip from a few hundred feet to as much as 3,000 feet below land surface. The aquifers are fractured parallel to the strike of bedding, allowing for a preferential flow of water parallel to strike.

For the purposes of modeling, the Site geology may be divided into four broad categories: unconsolidated overburden, shallow weathered bedrock, intermediate and deep fractured bedrock. A more detailed discussion of the Site's geology is provided in Section 2.3.3 of the Focused Feasibility Study Report.

L.5.2 *Water Balance*

In order to define the model it was necessary to evaluate the rate at which ground water is recharged by precipitation infiltration and the relationship between streams and ground water. As will be shown during the discussion of model calibration and sensitivity, the calibration of the model is highly dependent upon the rate of infiltration.

On an annual basis the total stream discharge within a drainage basin is equal to the total precipitation infiltration plus surface runoff. Over a long term, inputs to the regional hydrologic system are balanced by outputs. An annual water balance is generally expressed as:

$$P = I + R + ET$$

where:

- P = annual precipitation (inches/year)
- I = annual infiltration (inches/year)
- R = surface runoff (inches/year)
- ET = evaporation and plant transpiration (inches/year)

The annual average precipitation, P, for the Middletown area is approximately 44 inches per year (Chow, 1964). Normal annual runoff for the region is approximately 20 inches per year (Linsley, 1979). The annual average evapotranspiration, ET, was estimated from climatological data to be approximately 12 inches per year (Linsley, 1979). Based on a regional water balance, the annual average infiltration rate is approximately 12 inches per year. The reasonable range of the annual infiltration rate was determined to be 6 to 18 inches per year, roughly 50% above or below the estimated average value. The regional modeling made the assumption that recharge was uniformly distributed.

L.5.3 *Aquifer Characteristics*

Meisler and Longwill (1961) reported the results of aquifer tests performed in 1959 at the Olmsted Air Force Base, Middletown, Pennsylvania. The wells tested include Da-78 in the North Base Landfill

Area (referred to as the Warehouse Area in the USGS Report), Da-81 (HIA-2) in the Eastern Area, Da-92 (HIA-13) in the Central Area, and Da-90 (HIA-11) in the Western Area. These tests were of relatively short duration.

Aquifer pumping tests were also performed as part of the SSI to evaluate the transmissivity of the bedrock aquifer in the same four general areas. Nominal 72-hour pumping or recovery tests were performed on wells HIA-2, HIA-13, HIA-9, and MID-04. The results of the SSI tests demonstrate that the transmissivity of the bedrock aquifer is increasing moving from the North Base Landfill Area toward the Industrial Area and from east to west. The Western Area exhibited an aquifer transmissivity approximately 25 times greater than the North Base Landfill Area. This is likely due to increased fracturing in the bedrock in the Western Area. The SSI results did not correlate well with the USGS studies. The difference is attributed primarily to the greater duration of the SSI tests which allowed testing of the aquifer over a larger scale than the USGS tests. The longer duration tests overcame some of the influences of heterogeneous aquifer conditions which significantly impact the aquifer response during the early portions of the test.

Based on Site geology, it was anticipated that anisotropic conditions would be observed during the capture zone test, i.e. that a greater drawdown would be observed in the direction of bedrock strike (ranges from N 5° E to N 65° E) versus the direction of dip. Observation wells were installed along strike and along dip to monitor this effect. However, anisotropic conditions were not indicated by the aquifer testing.

The calculated transmissivity value determined for each test area is as follows:

Eastern Area	HIA-2	230 ft^2/day
Central Area	HIA-13	1,100 ft^2/day
Western Area	HIA-9	3,200 ft^2/day
NBL Area	MID-04	130 ft^2/day

L.5.4 *Previous Modeling*

Ground water modeling was performed in the SSI and reported in Appendix K, "Capture Zone Tests and Analysis". The Capture Zone modeling used a 2-dimensional analytic element model, TWODAN (Fitts, 1994) which used the same basic regional conditions simulated by the

MODFLOW Model. The TWODAN model provided an excellent reference and starting point for the 3-D MODFLOW model discussed herein.

L.6 CONCEPTUAL MODEL

The model configuration is a 3-dimensional model that represents the Site as a porous medium even though there appears to be some fracture flow of ground water. The conceptual 2-D analytic element model presented in the Capture Zone Analysis was expanded to 3-D to incorporate the area geology (in cross sections), the aquifer bottom elevations, aquifer boundaries, and production well locations. This 3-D model is the basis for definition of the hydrogeologic conditions for the computer model input.

The characterization of the aquifer included potential ground water discharge to streams and an estimated rate of precipitation recharge to the aquifer. The conceptual model was constructed using regional and site-specific geologic information, on-site monitoring well data, production well data, regional climatic information, and stream elevation data from USGS topographic maps. The thirteen HIA production wells and five Middletown Borough production wells are located within the model area.

The conceptual model for the regional aquifer that surrounds the Middletown Airfield was based on the following:

1. Based on published geologic data, the regional aquifer (Gettysburg formation) within the modeled area was developed under a similar geological setting and experienced similar weathering and erosion conditions. As a result, the aquifer has generally similar hydraulic characteristics on the regional scale. However, the area along the Susquehanna River exhibits higher aquifer transmissivity than observed in the upland areas of the model based on the capture zone tests performed as part of the SSI. Therefore the transmissivity of the aquifer varies across the modeled area, from the highly conductive zone along the Susquehanna River, near wells HIA-9 and HIA-13, to the less conductive upland area, near MID-04.

3. The area geology (in cross sections), the aquifer bottom elevations, aquifer boundaries, and production well locations provided the basis for definition of the 3-D hydrogeologic conditions for the computer model input. The 3-D model is divided into 4 layers, representing the overburden, shallow bedrock, intermediate bedrock, and deep bedrock intervals.

4. The predominant source of ground water is infiltration from precipitation. Ground water generally flows toward surface water bodies, such as streams, ponds, and rivers, which have measurable

surface water elevations. On the regional scale, it is reasonable to assume that the infiltration rate is relatively uniform over the entire area.

5. The capture zone tests conducted at the Middletown Airfield found the aquifer is relatively isotropic, i.e. aquifer transmissivity is consistent in different orientations.

The model was calibrated to water level conditions and actual pumping configuration observed on 8 May 1995. The model scenarios were based on the annual average conditions, and all input parameters and output results represent annual average values.

L.7 MODEL SETUP AND INPUT PARAMETERS

L.7.1 Modeled Area

The MODFLOW model was developed as a regional ground water flow model. Regional modeling simulates an entire ground water drainage basin and incorporates natural aquifer boundaries. Modeling on a regional scale simulates a much larger area than the area of interest and results in a model with many more model cells than a model limited to the area of interest. However, the regional model provides a more realistic description of the aquifer, avoiding artificial model boundaries. The regional model is very sensitive to changes in aquifer properties and eliminates the possibility of significant errors in the calibration of regional aquifer transmissivity. By comparison, models of limited areas with artificial boundaries will allow calibration of a model with grossly unrealistic aquifer properties by allowing the boundaries to drive the calibration. These limited area models are generally not sensitive to changes in aquifer conductivity or areal recharge rates.

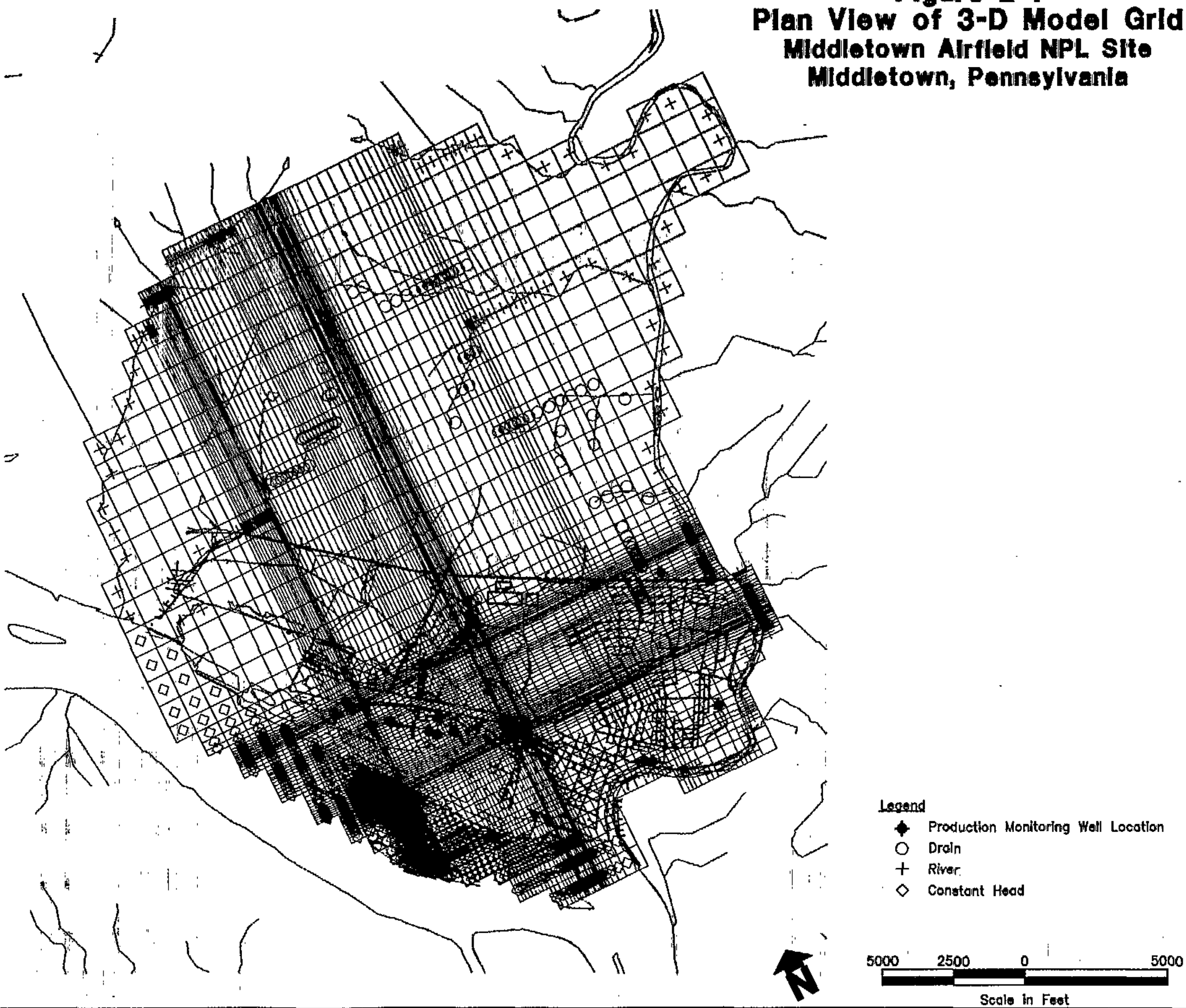
The MODFLOW model grid for the Middletown Airfield Site incorporates an area of approximately 17 square miles. The model grid was oriented in the direction of geologic strike and dip. This orientation provided the ability to incorporate anisotropic effects into the model. However, as anisotropy was not observed in the aquifer pumping tests, no anisotropy was incorporated into the final model.

Plate L.1 and Figure L-1 present the MODFLOW model grid. The model grid was constructed using the adaptive grid module of GMS. The grid cells are centered on the well coordinates with a minimum cell size of 20 feet, a bias of 1.4, and a maximum cell dimension of 1000 feet. The resulting grid is 84 rows by 93 columns. The site area including the North Base Landfill Area and the Industrial Area covers about 5.4 square miles.

L.7.2 Vertical Division of the Model Grid

The MODFLOW model was divided into four vertical layers corresponding to the overburden, shallow bedrock, intermediate bedrock, and deep bedrock intervals. The layers proceed from top

Figure L-1
Plan View of 3-D Model Grid
Middletown Airfield NPL Site
Middletown, Pennsylvania



(Layer 1) to bottom (Layer 4), as shown in Figure L-2. Layer 1 is unconfined and generally represents the overburden. The transmissivity of the layer is dependent on the saturated thickness of the layer. Layers 2 through 4 are confined. The transmissivity in these layers is independent of the water level in the aquifer.

Figure L-2 presents the vertical division of the aquifer relative to depth. The bedrock aquifer was divided vertically into three horizontal layers on the basis of the open intervals of the production wells. The shallow bedrock was assigned a thickness of 80 feet. The intermediate bedrock layer was assigned a thickness of 400 feet, which corresponds to the average open interval of the production wells. The deep bedrock layer was assigned a thickness of 180 feet. It should be recognized that, other than the bottom depth of the overburden/shallow aquifer, these depth divisions are not input to the model for Layers 2, 3, or 4. These layers are described to the model by their transmissivity, the product of hydraulic conductivity and layer thickness.

To begin the model, the transmissivity values determined from the SSI Capture Zone pumping tests, which represent the total bedrock aquifer $T_{bedrock}$, were used. The transmissivities of Layers 2 through 4 were assumed to contribute to the total aquifer transmissivity proportional to the defined layer thickness, i.e. that the hydraulic conductivity of each layer was identical. Thus, the following relationship was defined:

$$T_{bedrock} = T_2 + T_3 + T_4 \qquad \text{(L.7.2.1)}$$

where: $T_{bedrock}$ => total transmissivity of the bedrock aquifer
T_2, T_3, T_4 => transmissivity of layers 2, 3, & 4, respectively.

The transmissivity of a layer is given by:

$$T_i = K_i {}^* b_i \qquad \text{(L.7.2.2)}$$

where K_i = layer hydraulic conductivity, and
b_i = layer thickness.

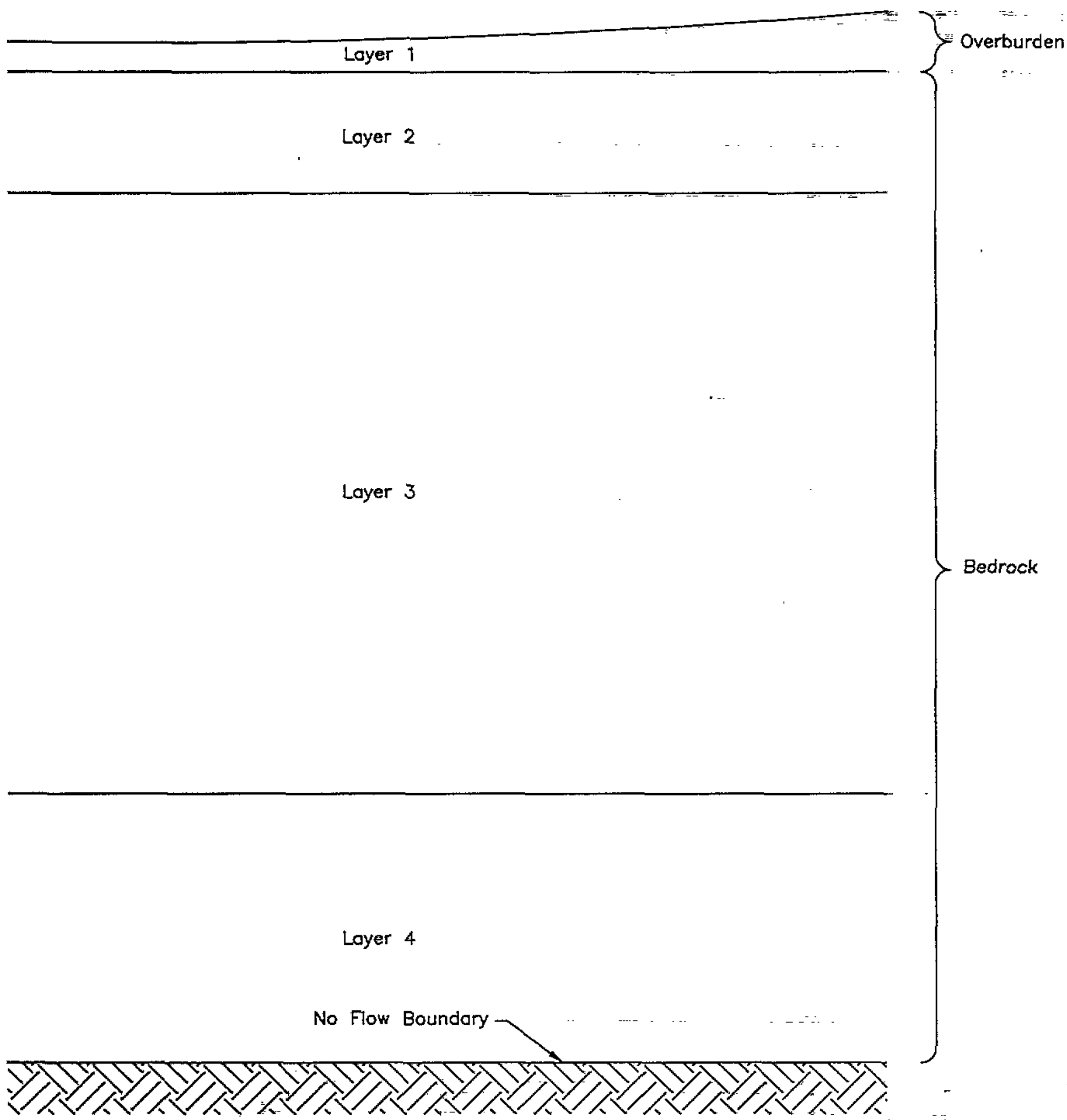
Then the transmissivity of the bedrock aquifer can be written:

$$T_{bedrock} = K_2{}^*b_2 + K_3{}^*b_3 + K_4{}^*b_4 \qquad \text{(L.7.2.3)}$$

Assuming that K is uniform in all layers, $K_{bedrock}$, then

$$T_i = K_{bedrock}{}^*b_i$$

Figure L-2
Side View of 3-D Model Grid
Middletown Airfield NPL Site
Middletown, Pennsylvania



$$T_{bedrock} = K_{bedrock}*b_2 + K_{bedrock}*b_3 + K_{bedrock}*b_4$$

$$T_{bedrock} = K_{bedrock}*(b_2+b_3+b_4)$$

or

$$K_{bedrock} = T_{bedrock}/(b_2+b_3+b_4) \qquad (L.7.2.4)$$

Given this relationship, the transmissivity initially defined for layers 2, 3, and 4 is given by:

$$T_i = T_{bedrock} * b_i/(b_2+b_3+b_4) \qquad (L.7.2.5)$$

Figure L-3 shows the transmissivity of the bedrock determined from the Capture Zone Pumping tests and based on the 2-D modeling results from the Capture Zone Modeling. The transmissivity values determined from the capture zone tests were input to a contouring routine in GMS along with several "control" points based on the 2-D modeling. These points were then contoured to produce a smoothly changing aquifer transmissivity, $T_{bedrock}$.

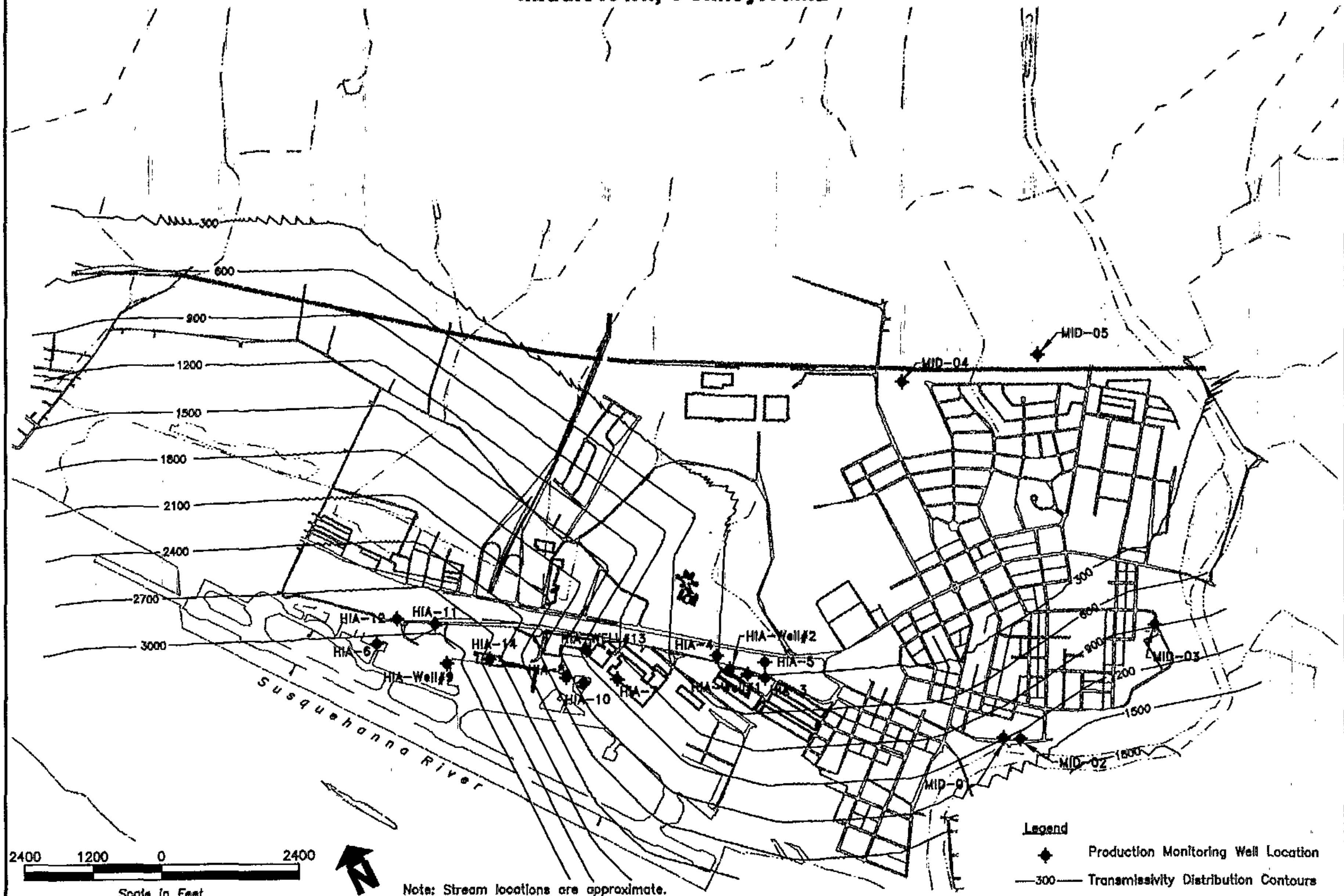
The aquifer transmissivity from the contouring, Figure L-3, was input into each model layer and adjusted for each layer by multiplying by the factor, $b_i/(b_2+b_3+b_4)$, from equation L.7.2.5 above. Using this procedure, transmissivity adjustments could be made by changing one control point, recontouring the transmissivity points, and applying the contour results to all three layers.

The same contoured transmissivity data used to define layer transmissivities, Figure L-3, were used to develop vertical conductance values between layers. The ratio of vertical to horizontal conductivity was 1:100. Using the relative thicknesses of the bedrock layers, the vertical conductance of each layer was determined from equation L.7.2.3 above.

Aquifer transmissivity values were based on the capture zone tests performed as part of the SSI. The representative transmissivity value for each test area is as follows:

Eastern Area	HIA-2	230 gpd/ft
Central Area	HIA-13	1,100 gpd/ft
Western Area	HIA-9	3,200 gpd/ft
NBL Area	MID-04	130 gpm/ft

Figure L-3
Transmissivity Distribution Across Model Area
Middletown Airfield NPL Site
Middletown, Pennsylvania



Note: Stream locations are approximate.

L.7.3 *Model Boundary Conditions*

L.7.3.1 *Layer 1 Stream Boundaries*

As discussed previously, a regional model was developed incorporating only natural aquifer boundaries. By simulating an entire ground water drainage basin, all ground water entered and left the model through Layer 1, the overburden/shallow aquifer. Figure L-8 presents the entire model grid and the model boundary conditions in Layer 1.

Streams were simulated using one of three possible conditions:

- Constant head: Only the Susquehanna River was simulated as a constant head boundary (all at elevation 280.00 ft msl). This is equivalent to a MODFLOW River boundary as long as the ground water level remains at or above the bottom of the river.
- River Cells: Perennial streams were simulated as river cells. These cells will contribute water to the aquifer in the case that the ground water levels drop below the surface water elevation.
- Drain Cells: Intermittent streams are best simulated as drain cells as opposed to River cells. Should the ground water drop below the drain elevation, the drain (stream) will go dry and will not contribute water to the aquifer.

Elevations of the stream cells in the model were determined from the 1:24,000 scale USGS quadrangle map.

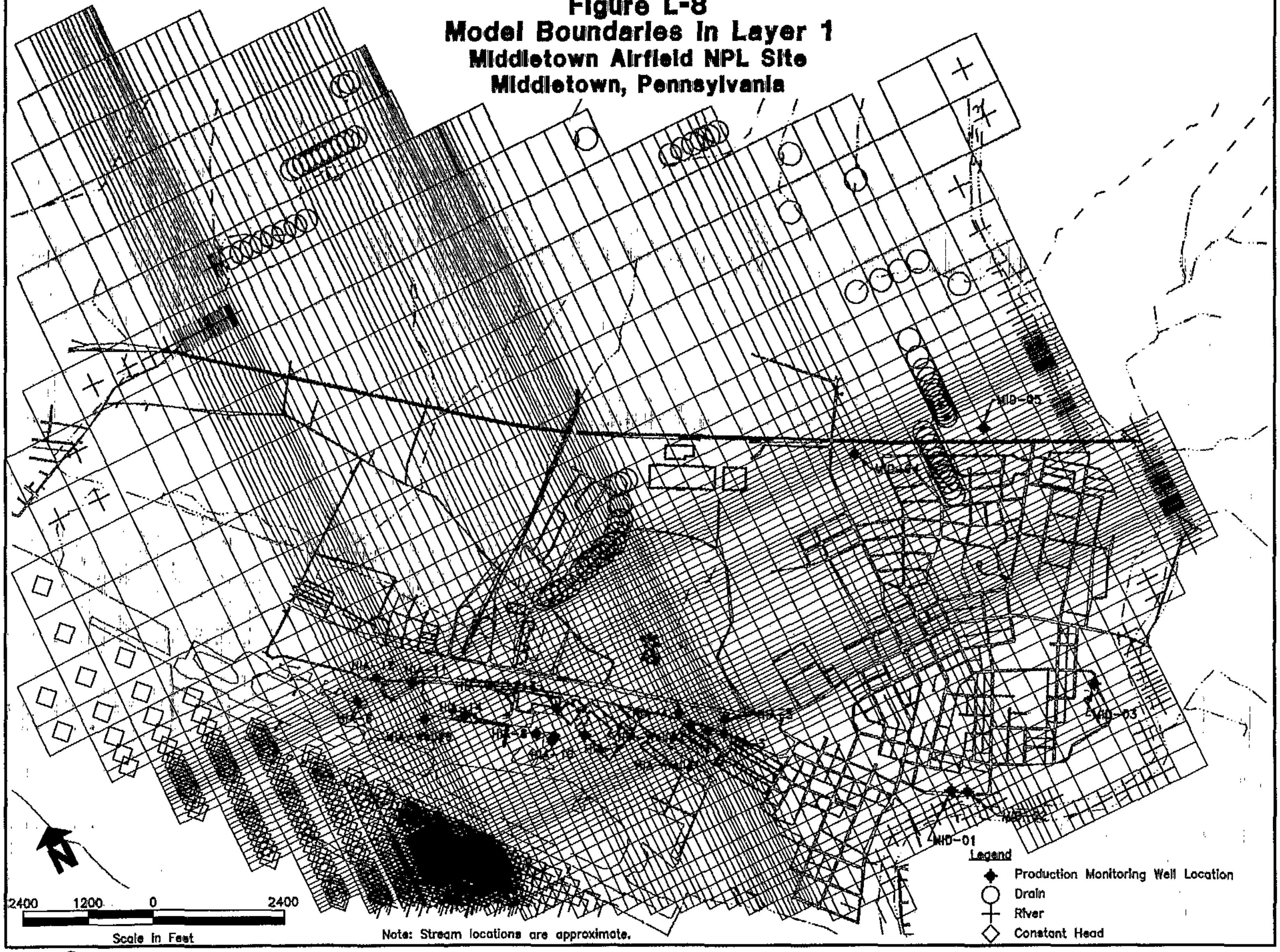
L.7.3.2 *Layer 1 Areal Recharge*

Precipitation recharge was applied uniformly across the model area at a rate of 10 inches per year.

L.7.3.3 *Layers 2, 3, and 4 Boundaries*

Layers 2, 3, and 4 have interlayer boundaries which communicate with the overlying or underlying layer. The production wells are located in Layer 3. The bottom of Layer 4 is a no-flow boundary. The side boundaries of these deep layers are fixed as no-flow boundaries at the limits of the active model area. The active model area in Layers 2, 3, and 4 is identical to the active area of Layer 1.

Figure L-8
Model Boundaries in Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania



Note: Stream locations are approximate.

L.7.3.4 Initial Conditions

The MODFLOW model was run in a steady-state simulation, which is most appropriate for evaluating the long term hydraulic influence of the HIA production wells on containment of ground water contamination. The model was calibrated to water level conditions and the actual pumping configuration observed on 8 May 1995. The model scenarios were based on the annual average conditions, and all input parameters and output results represent annual average values.

Table L-1 presents the annual average pumping rates of the HIA production wells for 1990 through 1995. Since the pumping configuration of the HIA production wells varies, the average over the 5 year period was used as a representative annual average. The Middletown wells MID-01, MID-02, MID-03, MID-04, and MID-05 operate at relatively consistent rates. Therefore the pumping rates of the Middletown Borough wells were based on the annual average rate in 1990 (GeoServices Ltd., 1992).

Table L-1
HIA Production Well Data
Middletown Airfield Site

Well	Average Gallons per Day						
	1990*	1991	1992	1993	1994	1995	5-year avg
HIA-1	21,405.5	63,759	41,942	36,351	64,256	49,658	46,229
HIA-2	40,346.8	79,205	72,380	67,255	72,474	67,598	66,543
HIA-3	12,157	5,926	11,889	835	0	73	5,147
HIA-4	556.2	504	56	75	731	80	334
HIA-5	15,816.7	28,942	34,120	23,578	13,289	731	19,413
HIA-6	116,405.5	92,479	108,228	100,187	51,164	115,441	97,317
HIA-9	26,457.5	21,153	12	28,741	10,833	24,565	18,627
HIA-11	77,515.1	96,984	164,967	171,521	124,252	114,795	125,006
HIA-12	139,279.5	131,293	145,758	108,575	129,420	168,390	137,119
HIA-13	323,202.5	335,877	247,792	258,500	313,991	197,645	279,501
HIA-14	230,843.8	282,781	218,661	182,551	201,074	236,088	225,333

Note: 1990 data for partial year. WTP on-line May 1990.

Well	Average Gallons per Minute						
	1990*	1991	1992	1993	1994	1995	5-year avg
HIA-1	14.9	44.3	29.1	25.2	44.6	34.5	32.1
HIA-2	28.0	55.0	50.3	46.7	50.3	46.9	46.2
HIA-3	8.4	4.1	8.3	0.6	0.0	0.1	3.6
HIA-4	0.4	0.4	0.0	0.1	0.5	0.1	0.2
HIA-5	11.0	20.1	23.7	16.4	9.2	0.5	13.5
HIA-6	80.8	64.2	75.2	69.6	35.5	80.2	67.6
HIA-9	18.4	14.7	0.0	20.0	7.5	17.1	12.9
HIA-11	53.8	67.4	114.6	119.1	86.3	79.7	86.8
HIA-12	96.7	91.2	101.2	75.4	89.9	116.9	95.2
HIA-13	224.4	233.2	172.1	179.5	218.0	137.3	194.1
HIA-14	160.3	196.4	151.8	126.8	139.6	164.0	156.5

Note: 1990 data for partial year. WTP on-line May 1990.

L.8 MODEL CALIBRATION

L.8.1 Reference Water Levels and Well Pumping Rates

The model was calibrated to the water level conditions observed and presented in the SSI. Ground water contour maps (Appendix C, Plates 7 and 8) developed from the water level measurements collected in May 1995, prior to the site-wide sampling event, were used to represent current conditions in the overburden and bedrock aquifers. Model calibration was performed by adjusting the hydraulic parameters of the aquifer, such as hydraulic conductivity, elevations of streams, stream bottom conductance, and recharge rate, in order to achieve a relative fit to observed conditions.

The calibrated model run included simulation of the pumping of several HIA wells in accordance with the actual configuration of the HIA wells at the time of the observed water levels and all five of the Middletown Borough wells.

The average pump rates of the HIA wells were based on records from the HIA Water Plant Daily Reports which records the total pumpage, duration of pumping, and pump rate for each production well (Table L-1). Since the HIA water system operates on an "on demand" basis, the wells are continuously cycling on and off. The average daily pump rate used in the computer model provide a realistic withdrawal amount, however, the simulated drawdown is somewhat less than observed from the field measurements.

The configuration of the HIA wells during this time period is as follows:

Operating Status (May 8-9, 1995)		Pump Rate (gpm)	Avg. Daily Rate (gpm)
Lead Well	HIA-13	423	243
2nd Lead	HIA-1	195	107
Lag Well	HIA-6	562	282
2nd Lag	HIA-12	642	41
HVAC	HIA-14	385	185

Based on the consistency of operation of the Middletown Borough wells, the annual average pump rates for MID-01 through MID-05 were used (Personal communication, Ken Klinepeter, Borough of Middletown). The annual average pump rates for the Middletown Borough wells are as follows:

MID-01	295 gpm
MID-02	214 gpm
MID-03	67 gpm
MID-04	89 gpm
MID-05	167 gpm

L.8.2 *Calibration Performance*

Comparison of the computer simulated water levels to the ground water levels observed in May 1995 during the SSI, was performed for both the overburden and intermediate layers. The difference between the observed and simulated ground water levels is known as the residual. The residuals are a direct measure of the model's ability to reproduce the observed hydraulic conditions, which is the goal of the model calibration. Transmissivity and vertical conductance parameters were adjusted until the residual or difference between the computer simulated and field measured water level elevations were within a reasonable range. Streambed and drain conductance values were set high such that these cells were essentially constant head cells in Layer 1.

The objective of calibrating the model is to reproduce the observed water levels in the area of interest within an error of one typical contour interval. In the HIA area, the contour interval is typically 2 feet. In the North Base area, the contour interval is typically 5 feet. (See Appendix C, Plates 7 and 8, Focused Feasibility Report, which illustrate the potentiometric surface contours observed in the overburden and bedrock aquifers on 8 May 1995). However, this goal must be tempered by the ability to achieve it in a heterogeneous aquifer system with wells of varying depths and varying pumping rates. Many of the residuals fell within the calibration target range. However, some of the residual values, especially in the North Base area, did not.

Figures L-4 through L-7 illustrate the simulated water level contours from the calibrated model run for layers 1 through 4,

Figure L-4
Simulated Heads in Layer 1 for Calibration Run
Middletown Airfield NPL Site
Middletown, Pennsylvania

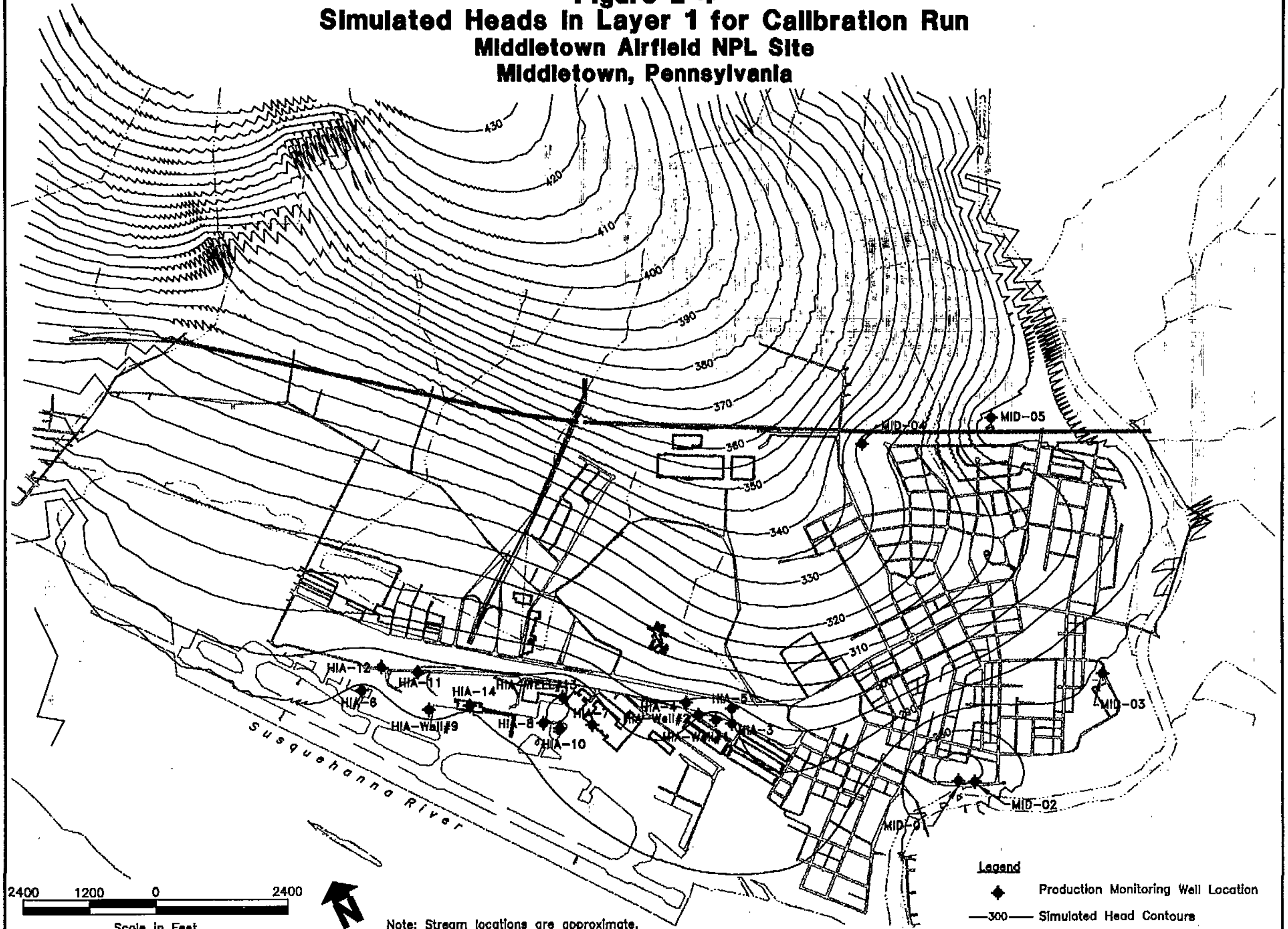


Figure L-5
Simulated Heads in Layer 2 for Calibration Run
Middletown Airfield NPL Site
Middletown, Pennsylvania

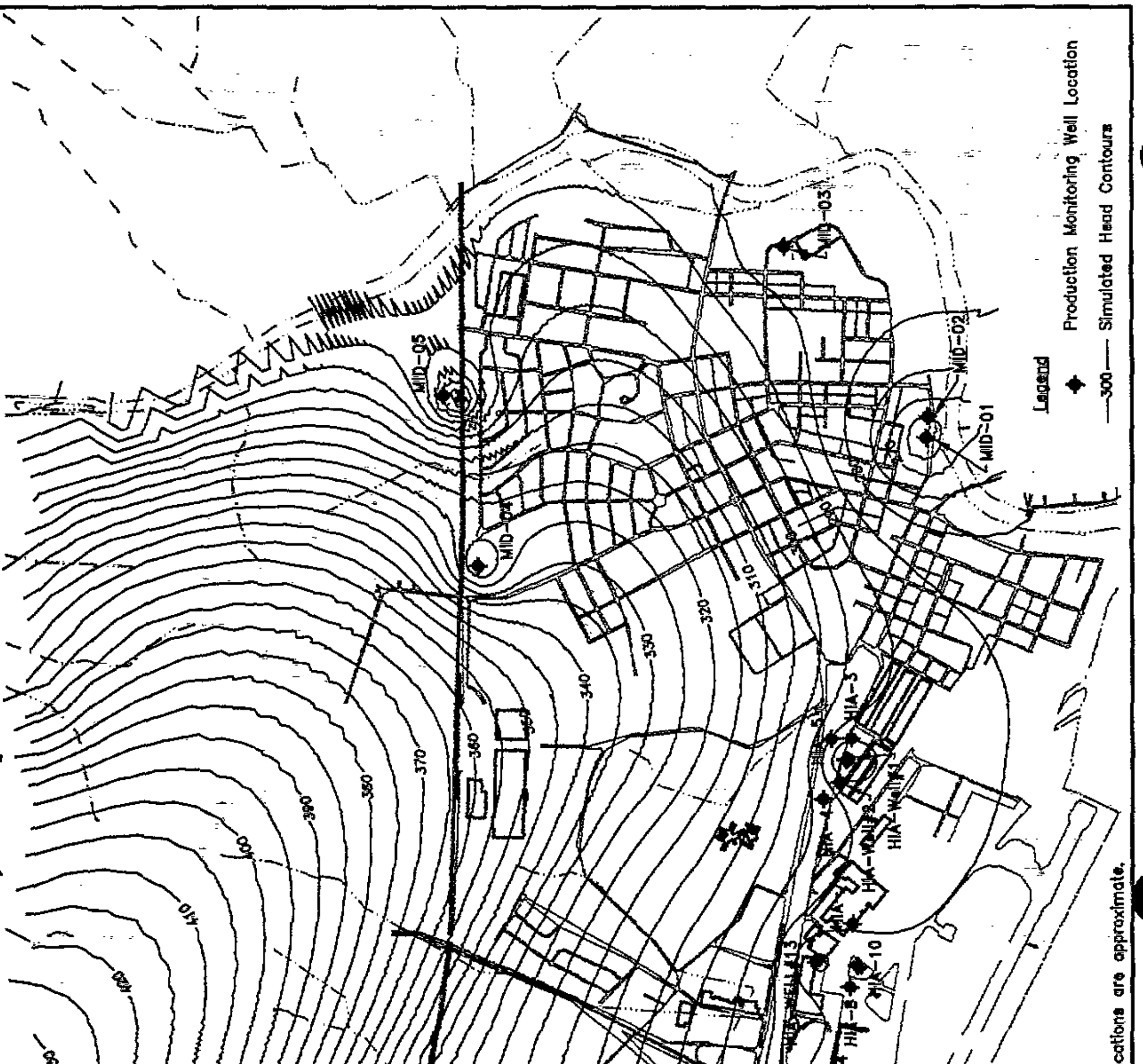


Figure L-6
Simulated Heads in Layer 3 for Calibration Run
Middletown Airfield NPL Site
Middletown, Pennsylvania

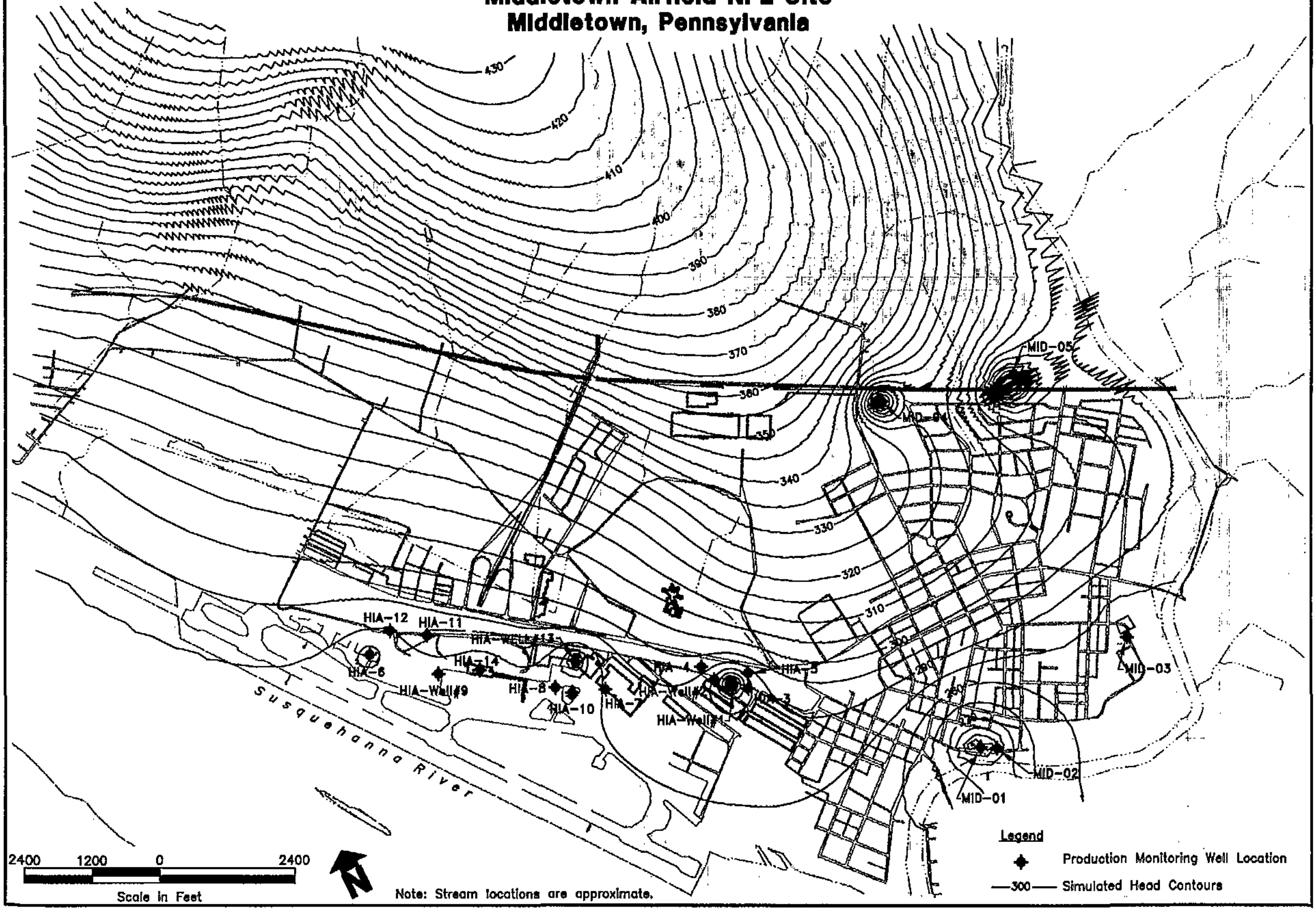
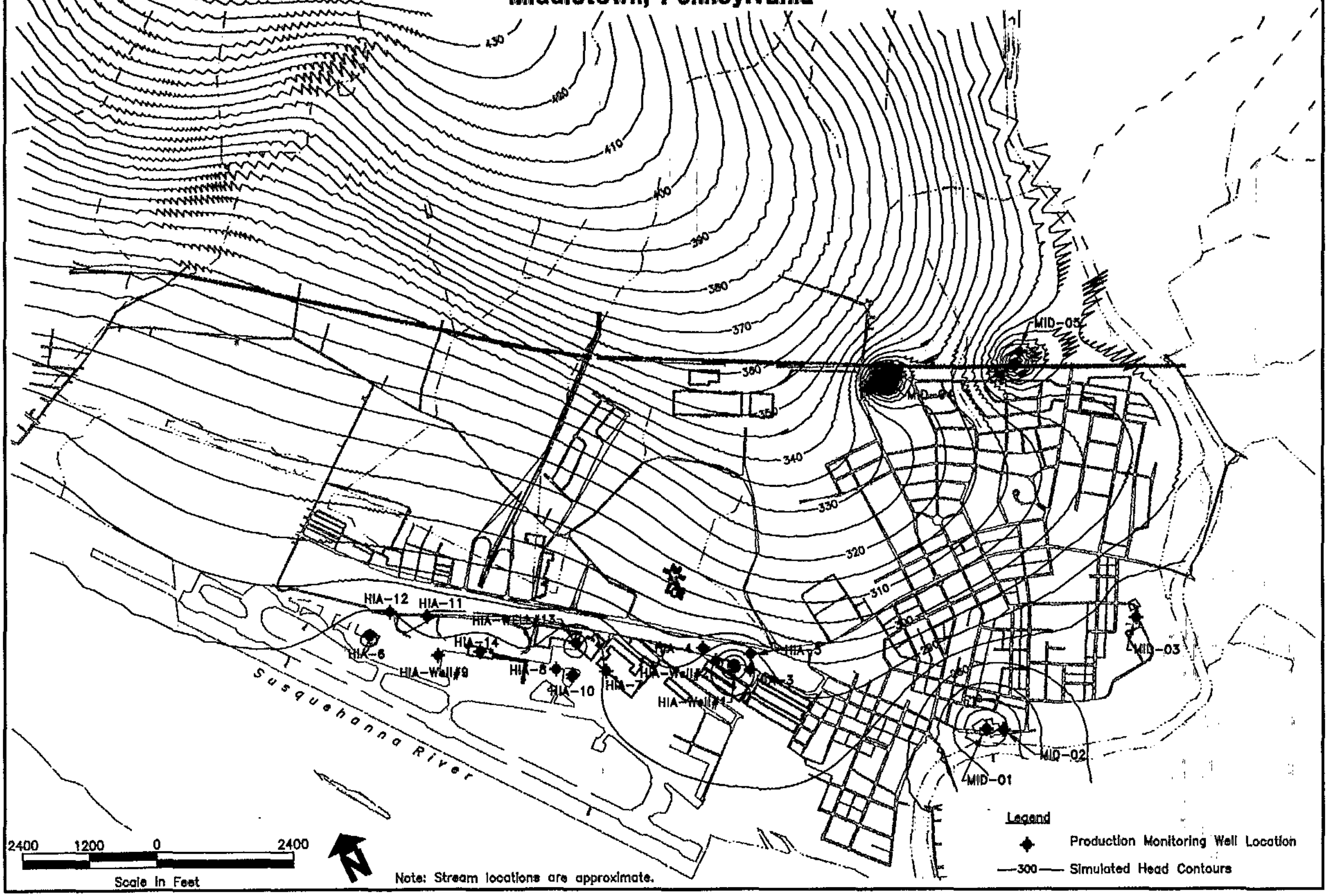


Figure L-7
Simulated Heads in Layer 4 for Calibration Run
Middletown Airfield NPL Site
Middletown, Pennsylvania



respectively. Figures L-9 and L-10 present bar charts of the residuals from the final calibration run for the shallow and intermediate zones (Layer 1 and 2), respectively. The wells are grouped such that the North Base Landfill wells are grouped along the left-hand side of the graph. Positive values indicate that the observed water levels were higher than the simulated, levels negative values occur where the observed water levels were lower than the simulated levels. Figures L-11 and L-12 present contours of the residuals for Layers 1 and 2, respectively. The residuals in the Industrial Area of the Site show a good match between the simulated heads and the observed water levels. The model simulated heads in the NBL Area are lower than the observed water levels.

The difficulties encountered in achieving residuals within the target of one contour interval is attributed to heterogeneous conditions within the aquifer, the "on-off" operation of the HIA production wells, and the presence of strong vertical gradients, especially in the North Base Landfill Area.

Figure L-9
Calibrated Model Residuals in Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania

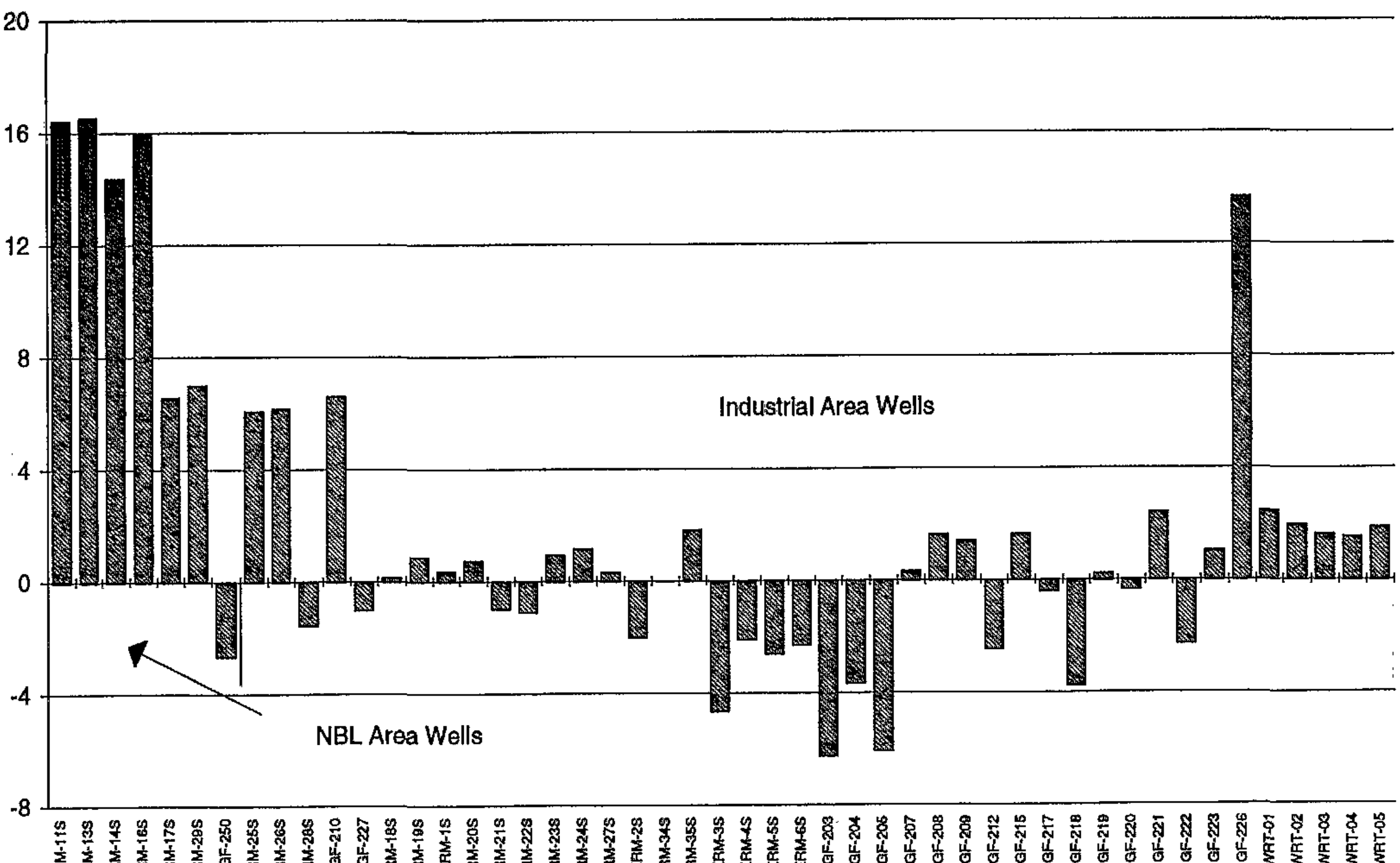


Figure L-10
Calibrated Model Residuals in Layer 2
Middletown Airfield NPL Site
Middletown, Pennsylvania

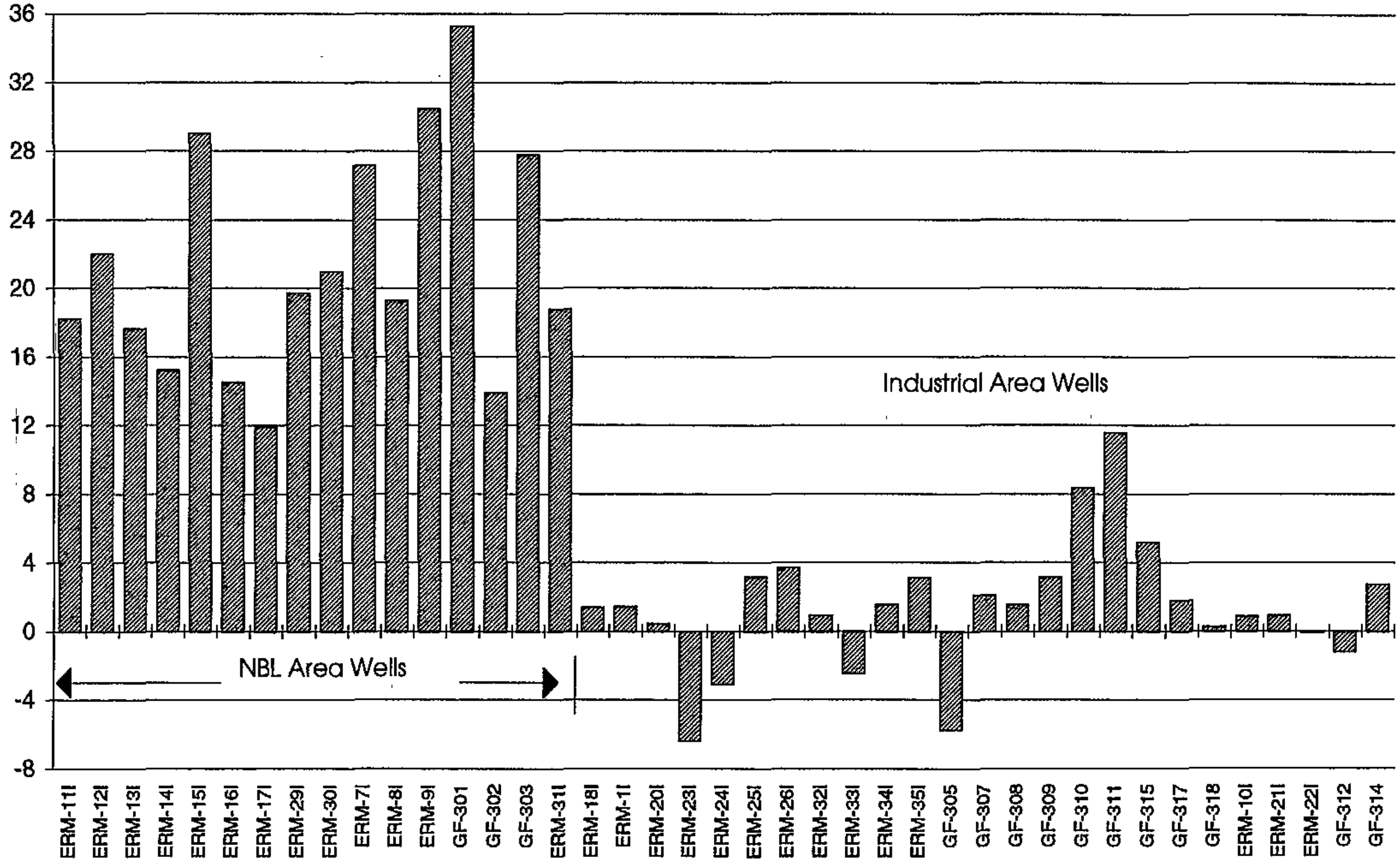
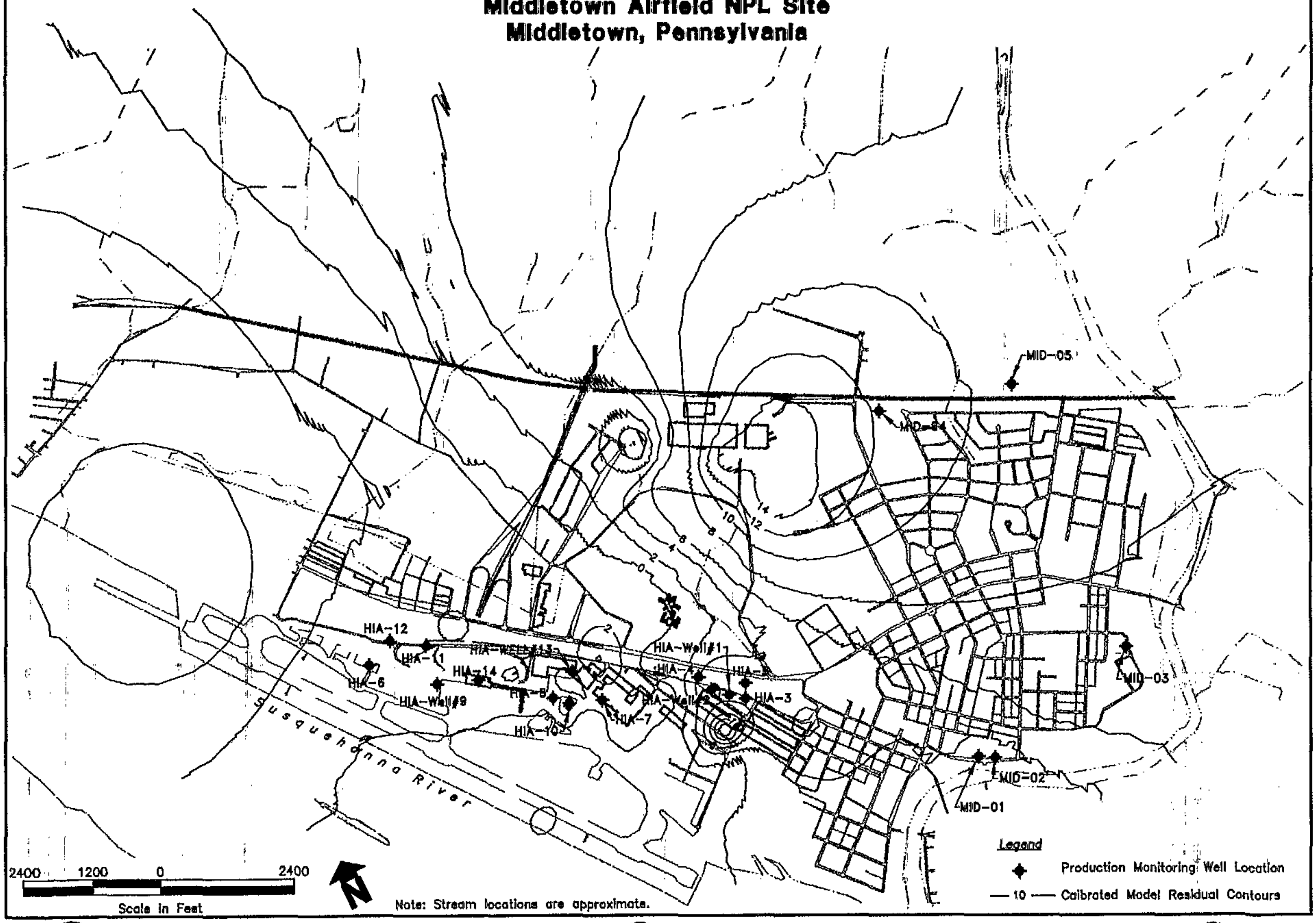


Figure L-11
Calibrated Model Residuals in Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania



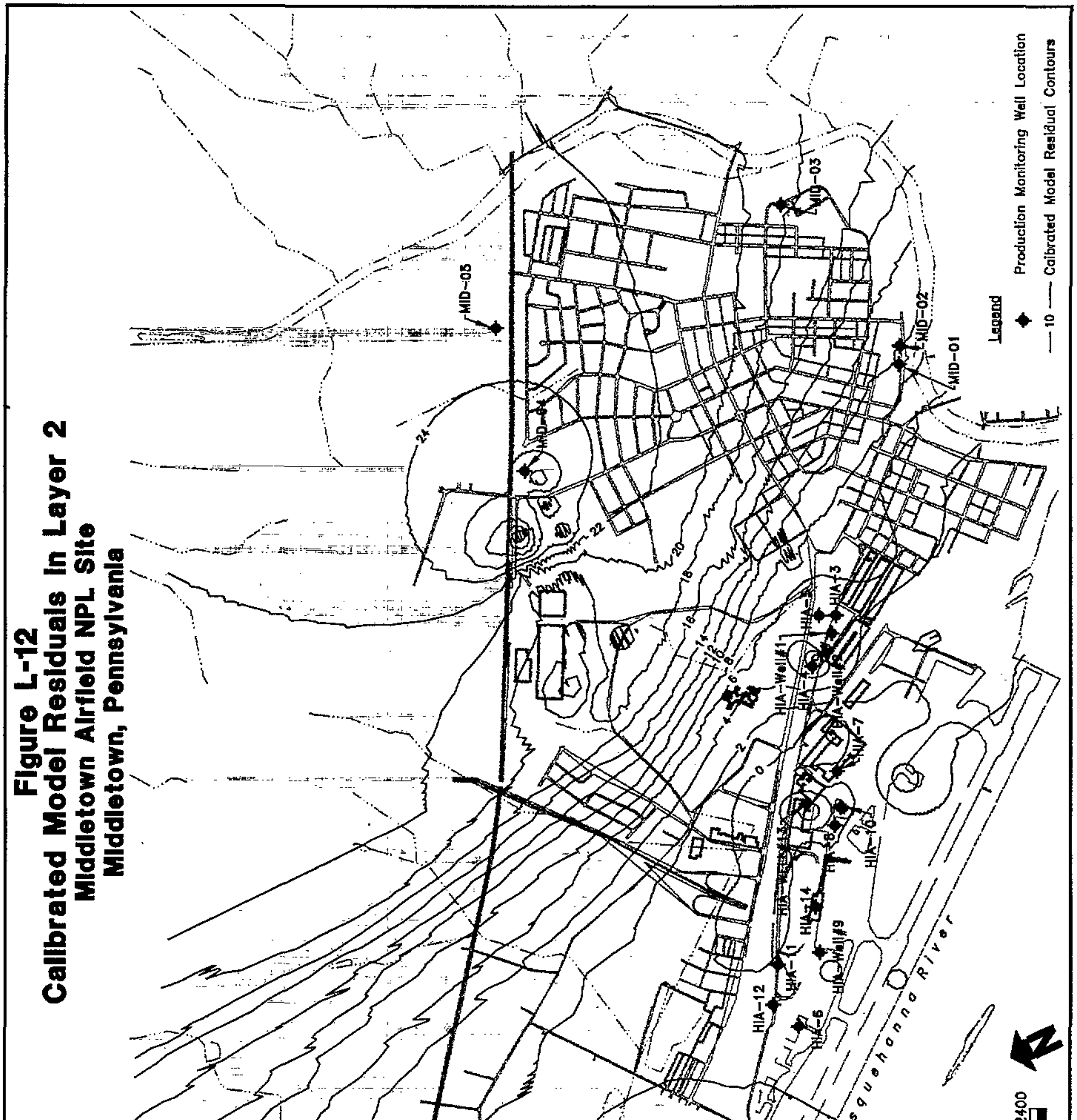


Figure L-12
Calibrated Model Residuals in Layer 2
Middletown Airfield NPL Site
Middletown, Pennsylvania
MID-05
MID-04
MID-03
MID-02
MID-01
HIA-3
HIA-Well#1
HIA-7
HIA-10
HIA-14
HIA-Well#9
HIA-11
HIA-12
HIA-6
Susquehanna River
Legend
Production Monitoring Well Location
10 Calibrated Model Residual Contours
2400 1200 0 2400
Scale in Feet
N

L.9 SENSITIVITY ANALYSIS

The next step was to perform a sensitivity analysis of the ground water flow model by varying the model parameters and determining the impact on the model results. Model parameters evaluated in the sensitivity analysis include hydraulic conductivity, vertical leakance between layers, and the regional infiltration rate.

L.9.1 Transmissivity and Areal Recharge

As discussed previously, the regional modeling approach produces a very sensitive model which results in a reliable calibration of regional transmissivity. Once calibration is achieved, if the aquifer hydraulic properties and areal recharge values are is increased or decreased, such that the ratio of transmissivity to areal recharge rate is held constant, then the heads in the model will not change. However, changing either of these parameters independently will result in a significant change in the simulated water levels.

Figure L-13 illustrates the results of increasing or decreasing transmissivity and areal recharge while maintaining a constant ratio of transmissivity, (hydraulic conductivity in Layer 1 and vertical conductance) to areal recharge. Three sets of model residuals (observed head-simulated head) for the wells measured during the SSI are shown. One set represents a decrease in the aquifer hydraulic properties by a factor of 50% with a 50% decrease in areal recharge (i.e. the ratio of transmissivity to areal recharge is held constant), one set of bars represents the calibrated model, and one set represents a 50% increase in the aquifer hydraulic properties and areal recharge. As expected, there are no significant differences between the three runs, as long as the transmissivity to areal recharge ratio is held constant.

Because the aquifer heads are proportional to the ratio of transmissivity to areal recharge, only one of these values needs to be changed in a regional model to test sensitivity to these variables. Because areal recharge is easily changed, it was varied while the hydraulic properties of the aquifer remained fixed at the calibrated values. Figure L-14 presents the residuals for a 50% decrease and a 50% increase in the areal recharge compared to the calibrated areal recharge in Layer 1. It can be seen that the model is

Figure L-13
Comparison of Residuals for Sensitivity Analysis of Transmissivity/Recharge Ratio in Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania

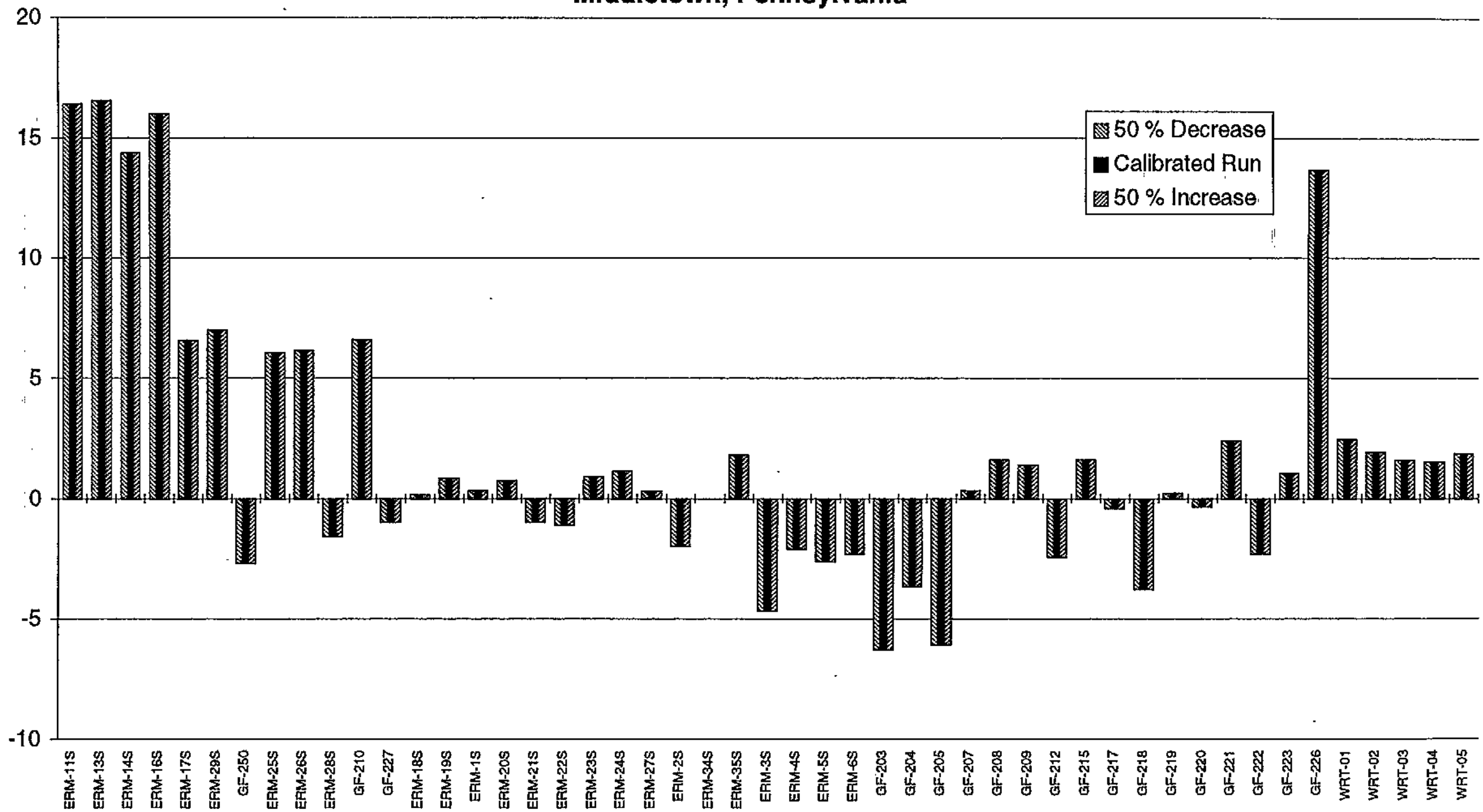
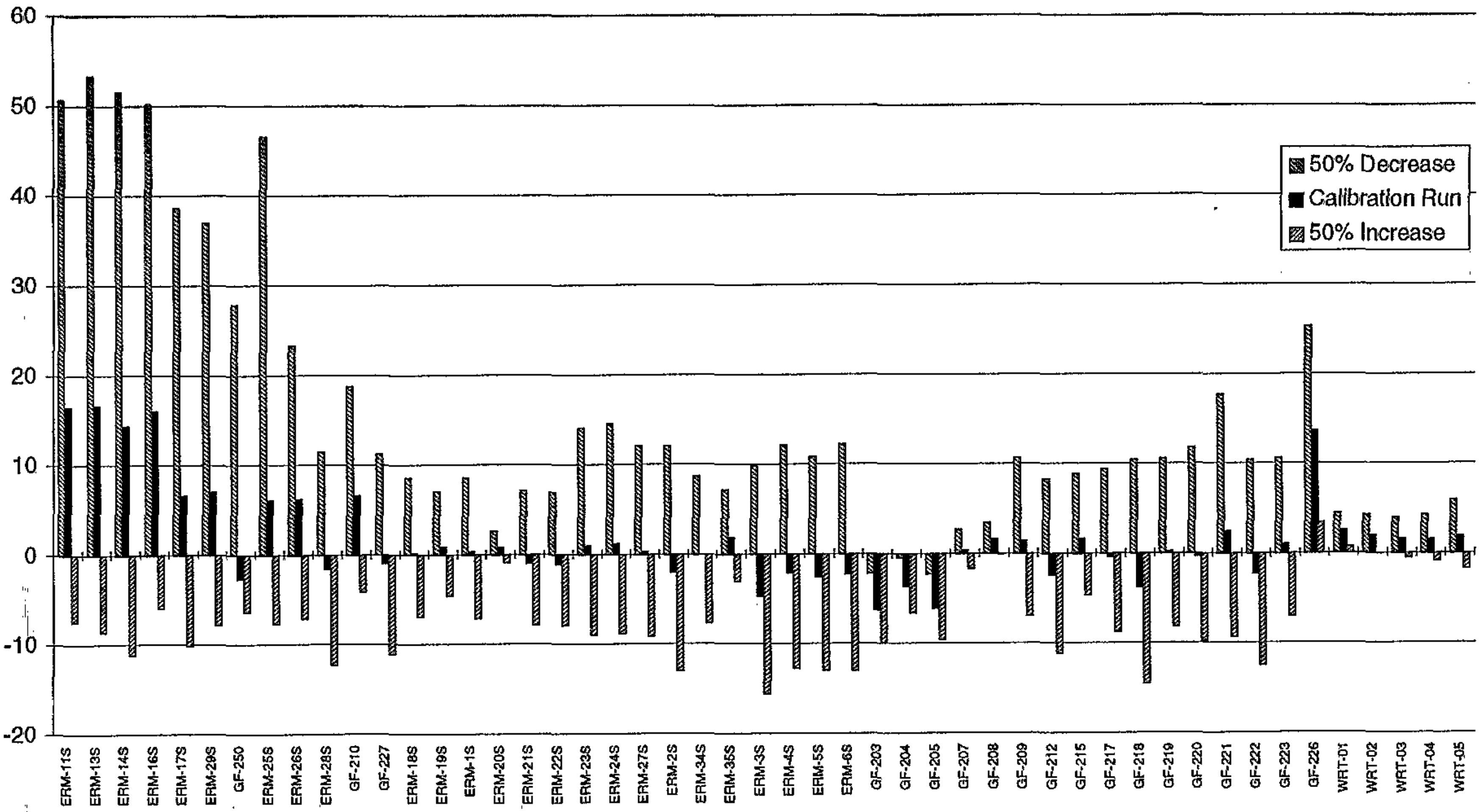


Figure L-14
Comparison of Residuals for Sensitivity Analysis of Recharge Rate in Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania



sensitive to changing areal recharge. The lower recharge rate results in lower simulated water levels (higher positive residuals) whereas increasing the recharge rate results in higher simulated water levels (negative residuals). The magnitude of the change is related to the aquifer transmissivity, however, it is not directly proportional to the transmissivity.

L.9.2 *Vertical Conductance*

In the discussion and sensitivity analyses presented in Section L.9.1, the aquifer parameters transmissivity and vertical conductance were adjusted proportionally with areal recharge to demonstrate how these parameters are "linked" together in the regional model, as they are in a natural system. An evaluation of the sensitivity of the model to variations in vertical conductance without changing the aquifer transmissivity or areal recharge was performed. Figures L-15 and L-16 show how changing the vertical conductance impacts the water levels in Layers 1 and 2, respectively. Three simulations are presented on each of these figures, one shows the calibrated run with an effective ratio of horizontal to vertical hydraulic conductivity, Kh:Kv, of 100:1, the other simulations show Kh:Kv ratios of 150:1 and 50:1.

Based on the results shown on Figures L-15 and L-16, the Kh:Kv ratio is relatively sensitive parameter. The higher Kh:Kv ratio of 150:1 resulted in lower simulated ground water levels in Layers 1 and 2 (higher positive residuals between the observed and simulated water levels). The greatest impact to water levels occurs in the NBL area. The magnitude of the change appears to be a function of distance from the river and the transmissivity of the aquifer. Thus ground water levels are very sensitive in the NBL area and relatively insensitive in the Industrial area. The greatest sensitivity in the Industrial area was in the immediate vicinity of the pumping well HIA-13. It is expected that the greatest effect would be observed where the vertical gradients are the largest, as in the immediate vicinity of a pumping well. Well nests ERM-23 and ERM-24 (approximately 100 feet from HIA-13) show a greater sensitivity to the Kh:Kv ratio than wells ERM-10I, 18I, and 33I (over 500 feet from HIA-13).

Figure L-15
Comparison of Residuals for Sensitivity Analysis of Kh:Kv ratio in Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania

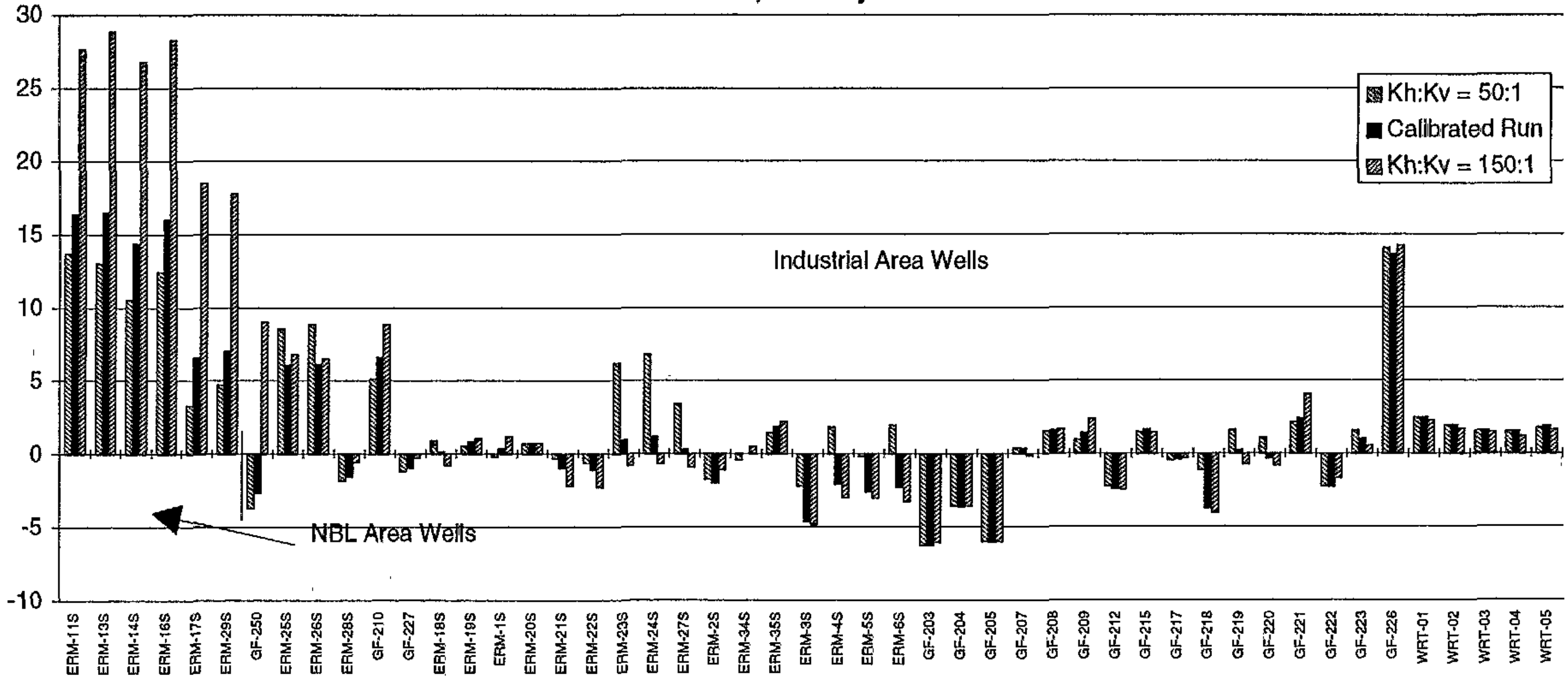
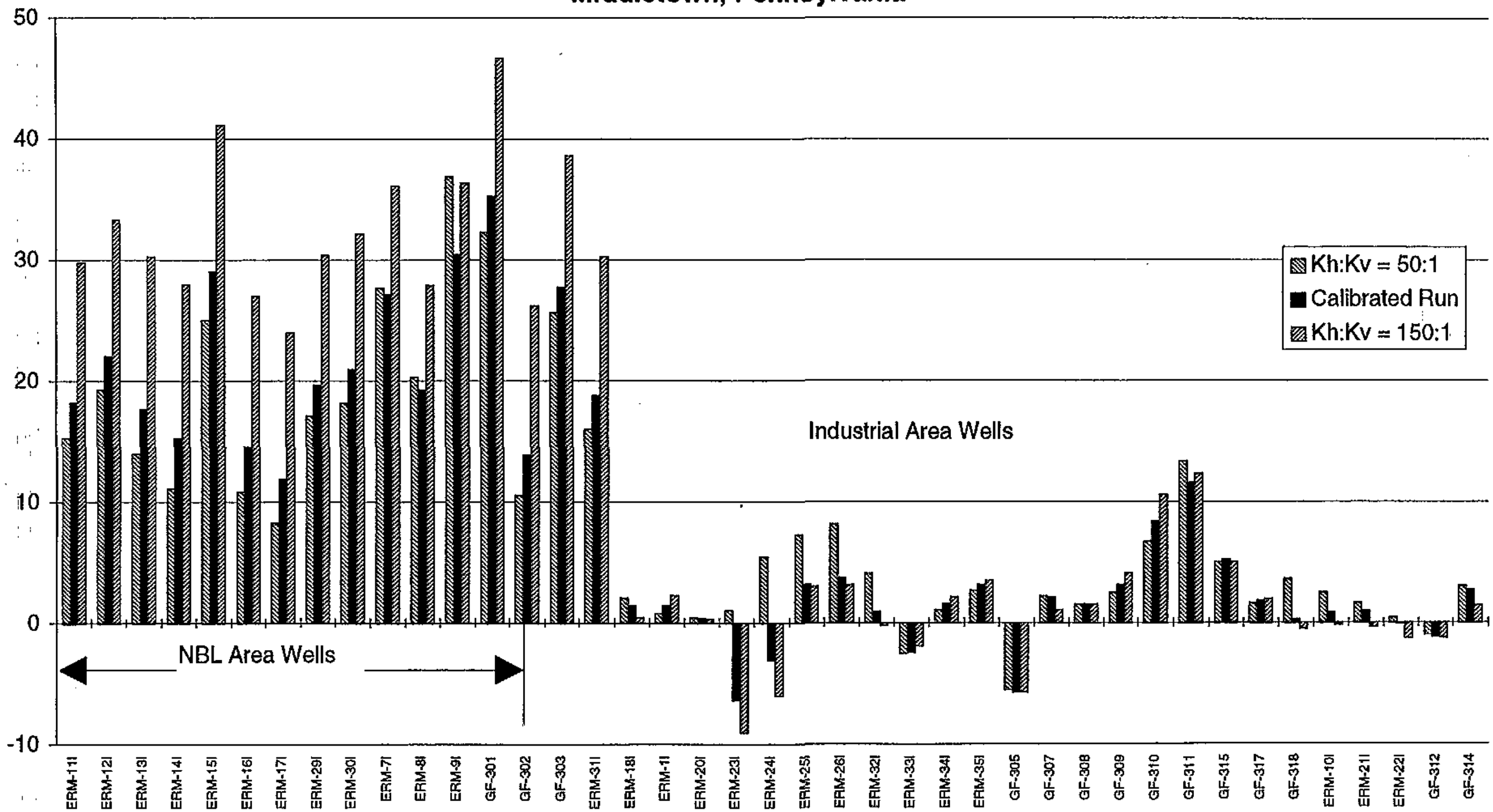


Figure L-16
Comparison of Residuals for Sensitivity Analysis of Kh:Kv ratio in Layer 2
Middletown Airfield NPL Site
Middletown, Pennsylvania



L.10 MODELING SCENARIOS

The objective of the modeling is to evaluate the hydraulic containment of the plume using the HIA production wells.

Three modeling scenarios including the simulation of current conditions and reconfiguration of the HIA production wells were performed. The modeling scenarios, as detailed in Section 2.2.5.3 of the Scope of Services, involving soil remediation and reconfigured wells and SVE remediation were not evaluated because no specific source areas were identified. It should be noted that two reconfiguration scenarios were simulated in addition to simulation of current conditions. The reconfiguration was based on knowledge of HIA operations, results of the current conditions simulations, and screening of several scenarios using the 2-D analytic element model developed during the capture zone analysis. All scenarios assume steady state conditions. Table L-2 presents the pumping rates for each scenario. Well pumping rates were simulated as annual averages.

L.10.1 *Scenario 1 - Current Conditions*

This scenario includes current HIA well configuration (average annual pumping rates for each HIA production well) with the operating air stripper, and the five Middletown wells, MID-01 through MID-05.

The total annual average pumping rate is 708.7 gpm from the HIA wells. The annual average pumping rate for the Middletown wells was 693 gpm. Figures L-17 through L-20 present the ground water contours generated model layers 1,2,3, and 4, respectively. Capture zones are depicted for Layers 2, 3, and 4. The capture zones for these three layers are identical, within the accuracy of the interpretation. This is reasonable considering the large screened intervals of the pumping wells and the large area of influence. The capture zones are similar to those determined for average annual pumping conditions using the TWODAN capture zone modeling (Scenario 4, Appendix K). The capture zones appear to overlap. However, there is a potential for some ground water to escape capture between the Eastern and Central area, and between HIA-13 and the Western area wells. None of the capture zones reach out to the Susquehanna River.

The capture zone in the unconfined overburden aquifer, Layer 1, is not depicted on Figure L-17. The modeled capture zone is very small and it's

Table L-2
Model Scenarios
Middletown Airfield NPL Site

Well	Model Cell (row, column)	Pump Rate (gallons per minute)		
		Scenario 1	Scenario 2	Scenario 3
HIA-1	24, 55	32.1	0.0	0.0
HIA-2	27, 52	46.2	0.0	0.0
HIA-3	21, 58	3.6	0.0	0.0
HIA-4	31, 50	0.2	0.0	0.0
HIA-5	25, 60	13.5	0.0	0.0
HIA-6	56, 10	67.6	91.4	67.6
HIA-9	48, 20	12.9	36.8	12.9
HIA-11	54, 22	86.8	110.7	86.8
HIA-12	59, 15	95.2	119.1	95.2
HIA-13	40, 34	194.1	194.1	194.1
HIA-14	45, 26	156.5	156.5	156.5
MID-01	8, 71	218.2	218.2	218.2
MID-02	7, 72	191.7	191.7	191.7
MID-03	11, 83	67.0	67.0	67.0
MID-04	56, 76	88.8	88.8	88.8
MID-05	49, 83	127.3	127.3	127.3

Figure L-17
Simulated Water Levels for Scenario 1 Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania

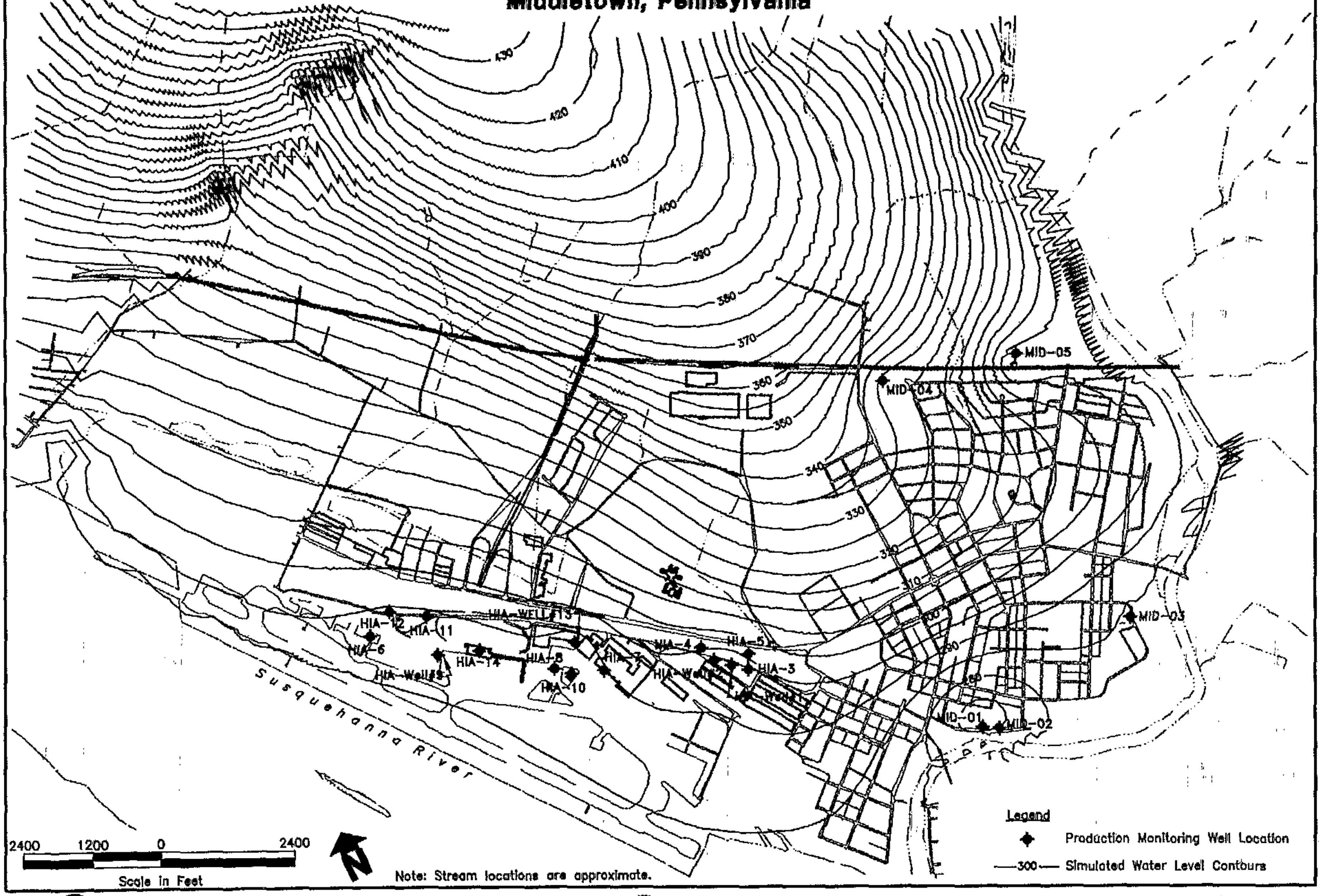


Figure L-18
Simulated Water Levels for Scenario 1 Layer 2
Middletown Airfield NPL Site
Middletown, Pennsylvania

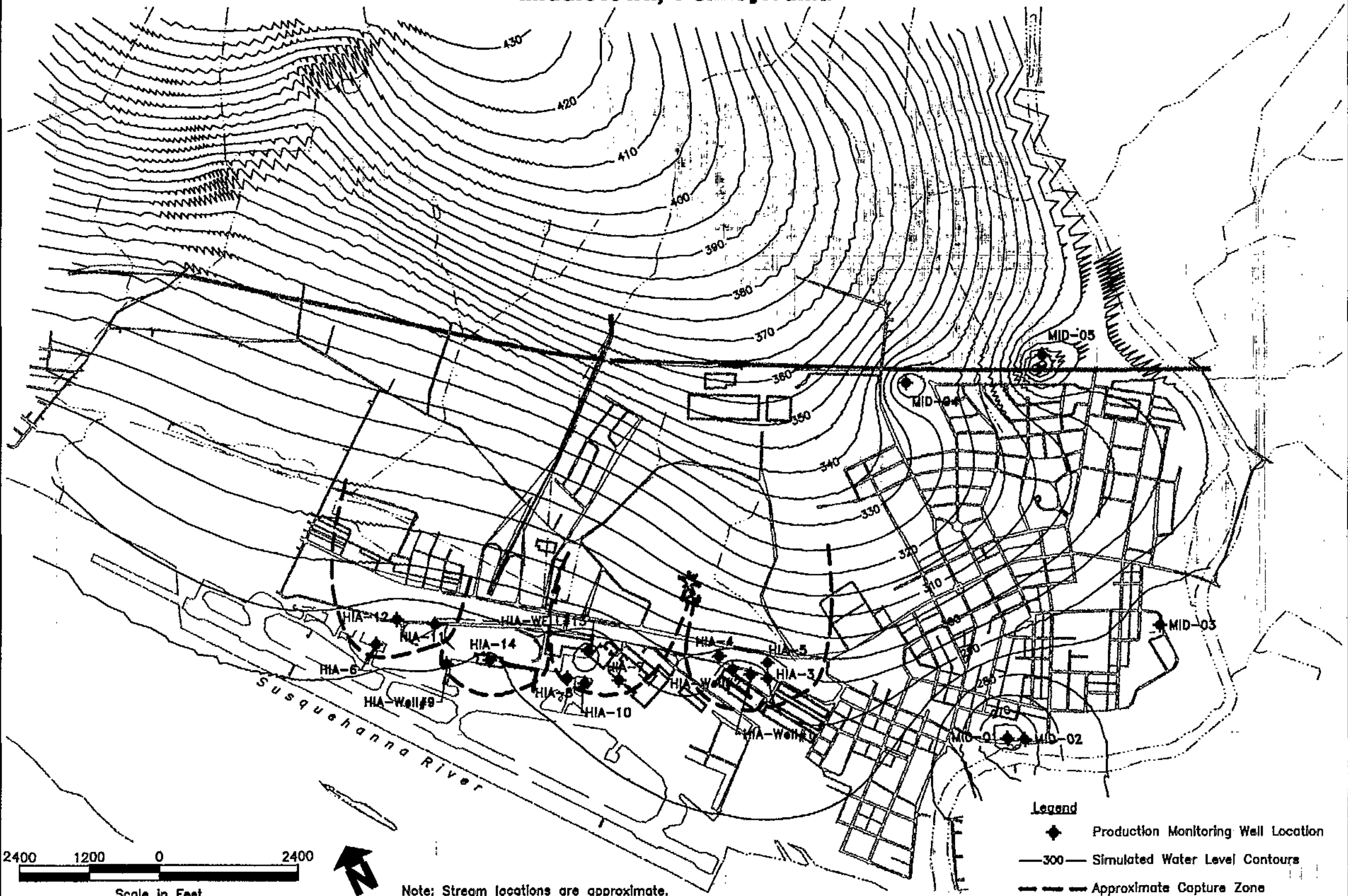
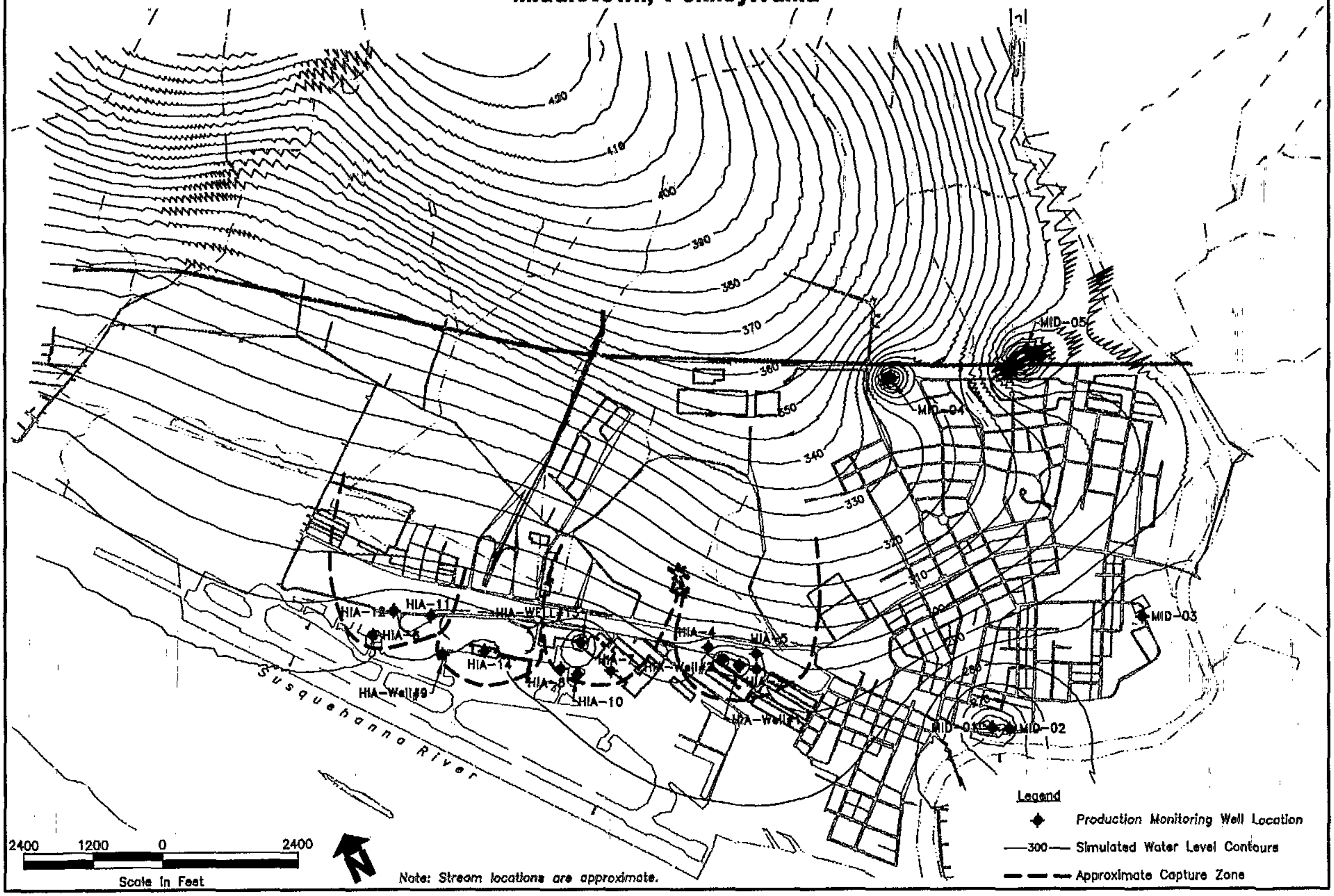


Figure L-19
Simulated Water Levels for Scenario 1 Layer 3
Middletown Airfield NPL Site
Middletown, Pennsylvania



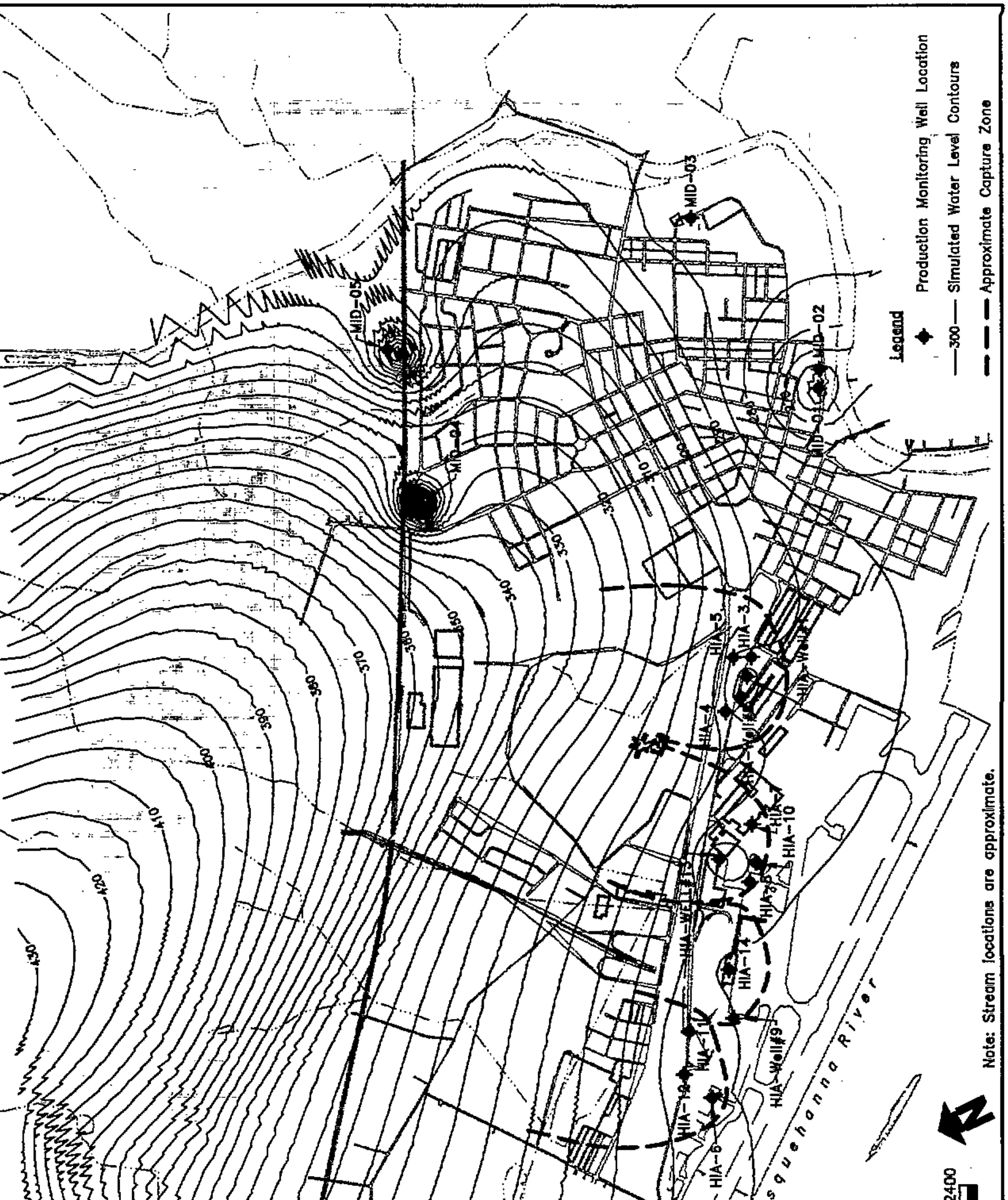


Figure L-20
Simulated Water Levels for Scenario 1 Layer 4
Middletown Airfield NPL Site
Middletown, Pennsylvania

width would be subject to significant uncertainty in the analysis. However, ground water contours produced for the SSI from May 1995 data (Plate 7 in the FFS report) suggest that HIA-13 has a significant capture area for the overburden aquifer. The difference between the modeled capture area and the observed is related to several factors:

- the pumping rate for HIA-13 during the May 1995 monitoring event was 423 gpm (when pumping) and average daily of 243 gpm for that day. The average annual pumping rate simulated for HIA-13 was 194 gpm.
- there had been a significant drought during and prior to the May 1995 monitoring event, and
- increasing the vertical conductance between model layers 1 and 2 may be necessary to allow the influence of pumping to have a greater impact on Layer 1.

L.10.2 *Scenario 2 - Reconfigured Wells*

This scenario includes reconfiguring the HIA wells such that the HIA wells in the Eastern Area (HIA-1 through HIA-5) are not pumping and compensating for the reduced pumping in the Eastern Area by increasing the pumping in the Western Area (HIA-6, HIA-9, HIA-11, and HIA-12). The total pumping rate for the HIA wells was maintained at the 708.7 gpm annual average rate. The wells in the Eastern area, HIA-1, -2, -3, -4, and -5, were turned off and their pumping volume was transferred to the Western Wells, HIA-6, -9, -11, and -12. The Eastern wells pump an annual average of 95.6 gpm. Figures L-21 through L-24 present the simulated ground water levels for layers 1, 2, 3, and 4, respectively. Capture zones are depicted for Layers 2, 3, and 4. As observed in Scenario 1, the capture zones for these three layers are identical, within the accuracy of the interpretation.

The result of transferring the pumping from the Eastern area to the Western area was to slightly increase the capture zone width and reach in the Western area and eliminate the capture zone of the Eastern wells entirely. The Western area and Central area capture zones now overlap with less potential for ground water escaping between HIA-13 and the Western wells than in Scenario 1.

Figure L-21
Simulated Water Levels for Scenario 2 Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania

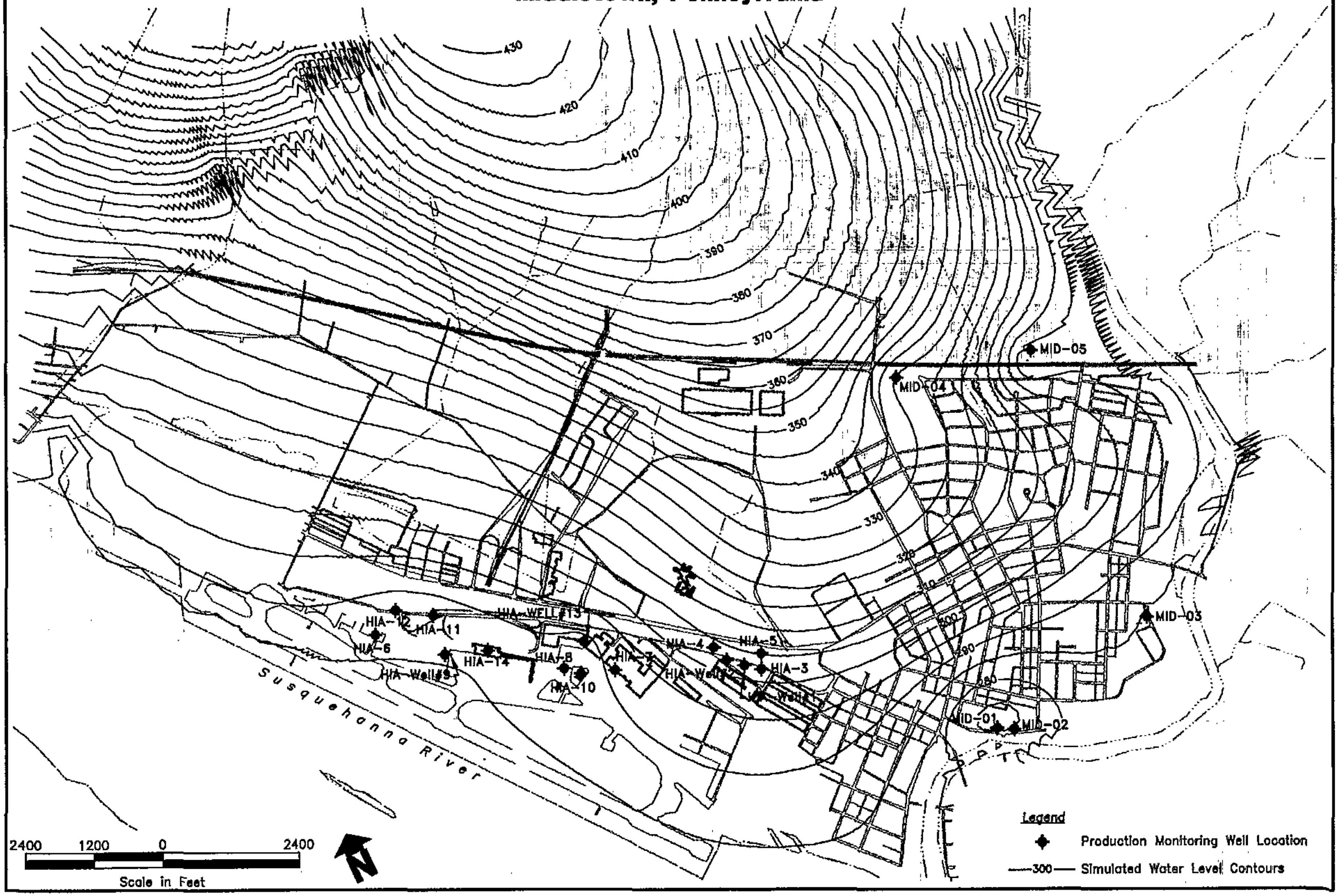


Figure L-22
Simulated Water Levels for Scenario 2 Layer 2
Middletown Airfield NPL Site
Middletown, Pennsylvania

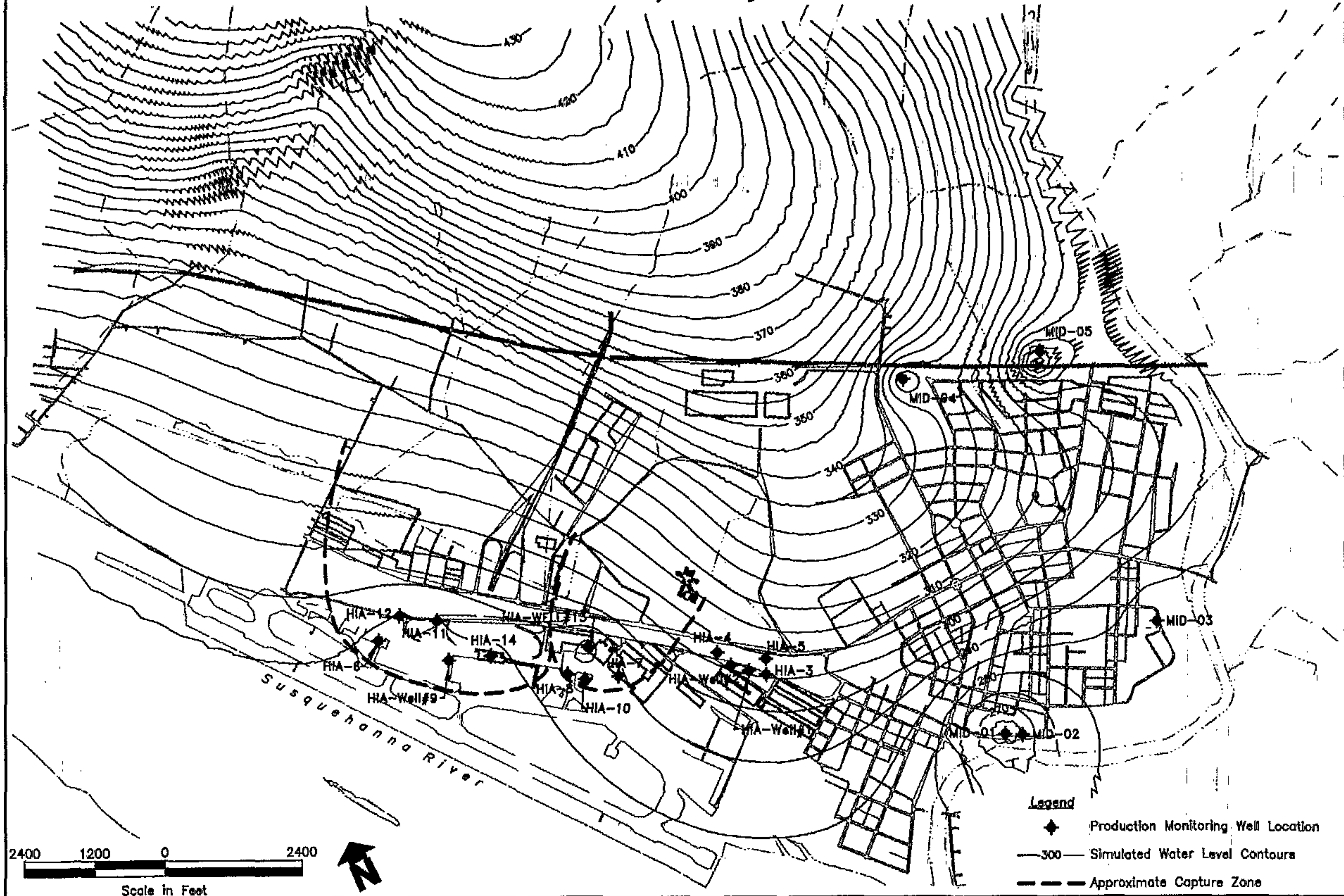


Figure L-23
Simulated Water Levels for Scenario 2 Layer 3
Middletown Airfield NPL Site
Middletown, Pennsylvania

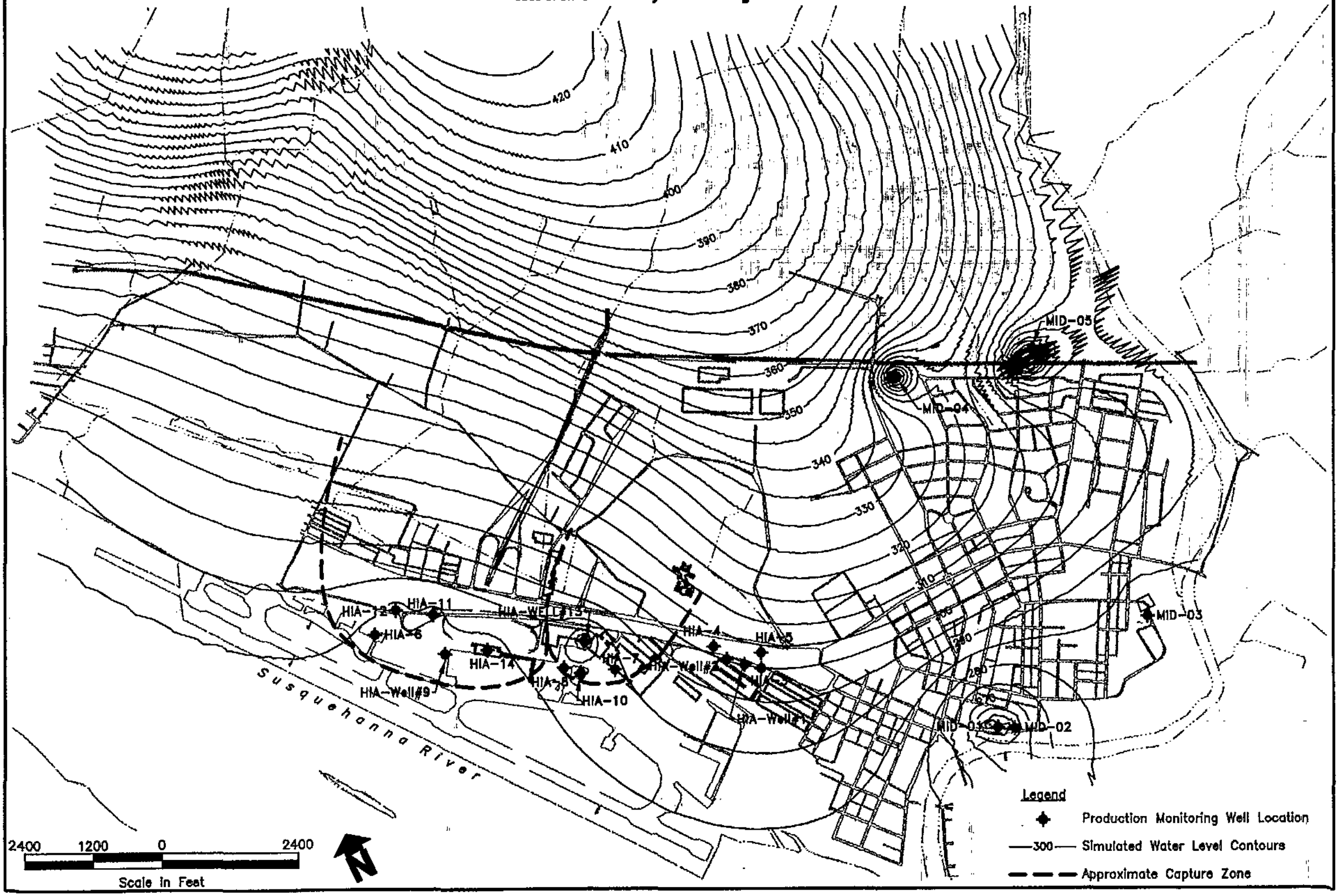
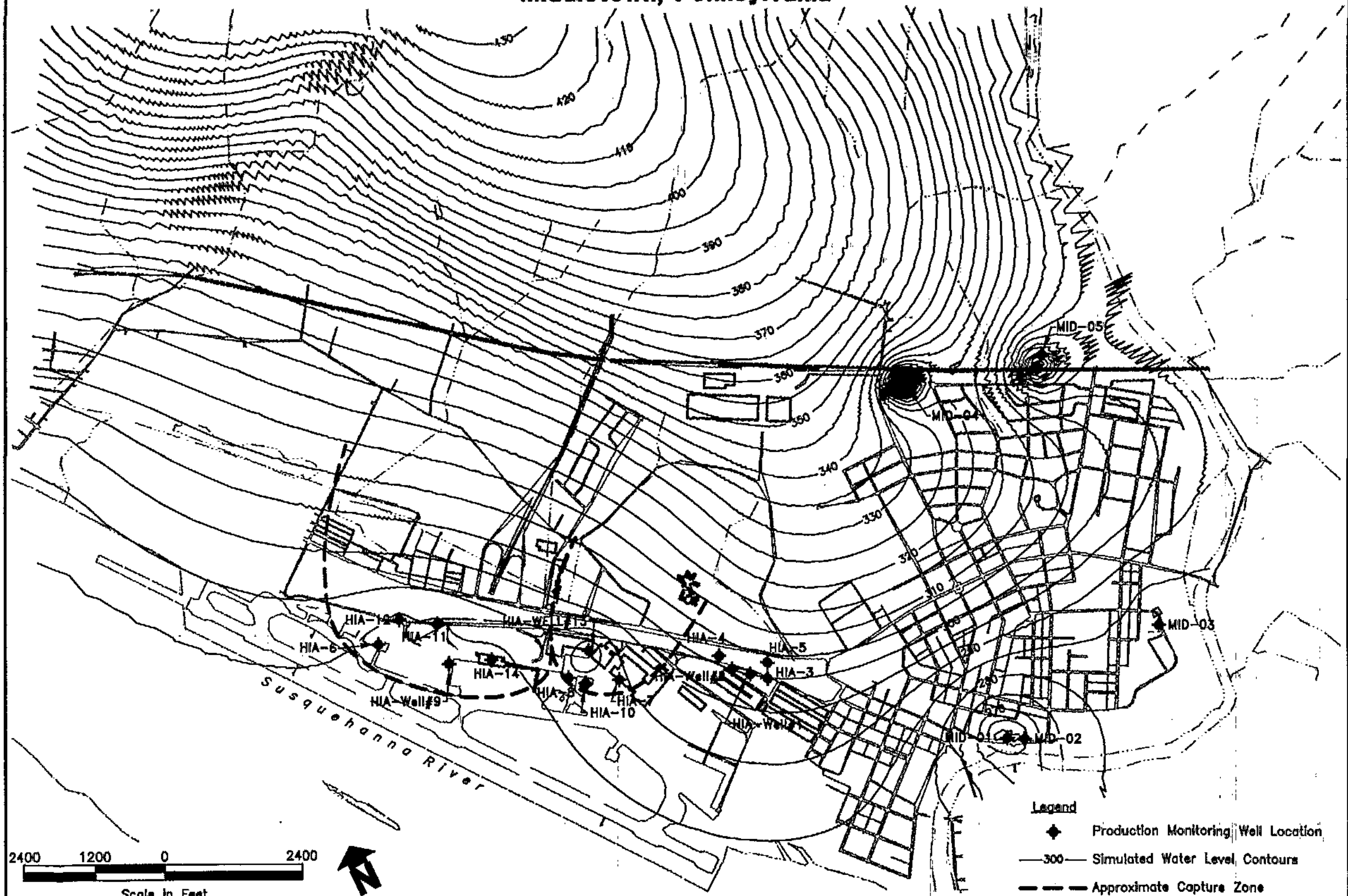


Figure L-24
Simulated Water Levels for Scenario 2 Layer 4
Middletown Airfield NPL Site
Middletown, Pennsylvania



L.10.3 *Scenario 3 Reduced HIA Pumping*

This scenario includes reconfiguring the HIA wells such that the HIA wells in the Eastern Area (HIA-1 through HIA-5) are not pumping and remaining HIA wells pump at their average annual rate (i.e. the total pumpage from the HIA wells is reduced by 95.6 gpm, the amount of pumpage from the Eastern Area). The pumping rates for the Middletown wells are the same as Scenarios 1 and 2. Figures L-25 through L-28 present the simulated ground water levels for layers 1, 2, 3, and 4, respectively. Capture zones are depicted for Layers 2, 3, and 4. As observed in Scenario 1, the capture zones for these three layers are identical, within the accuracy of the interpretation. The capture zones are essentially identical to those depicted in Scenario 1 for the Western and Central areas.

Figure L-25
Simulated Water Levels for Scenario 3 Layer 1
Middletown Airfield NPL Site
Middletown, Pennsylvania

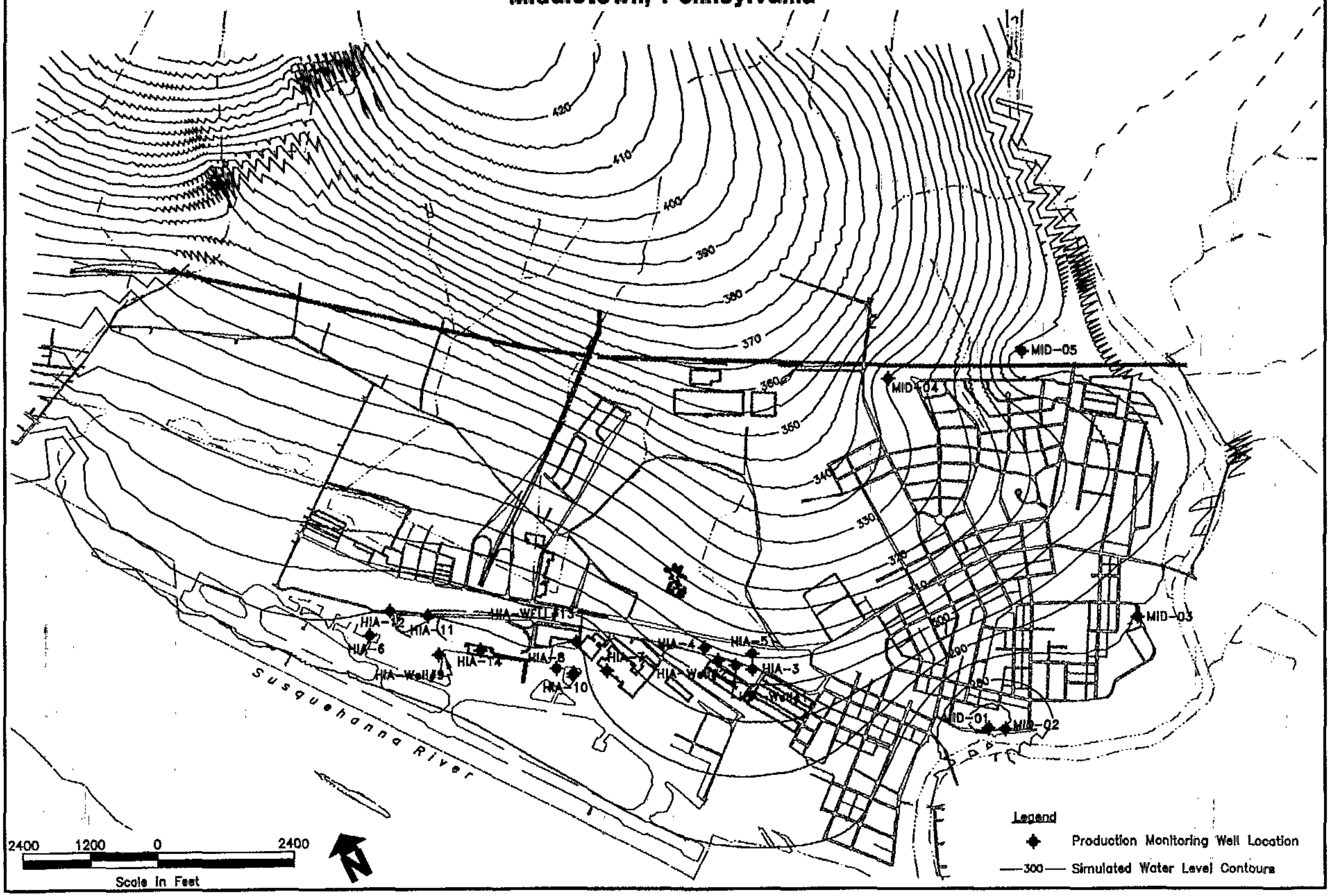


Figure L-26
Simulated Water Levels for Scenario 3 Layer 2
Middletown Airfield NPL Site
Middletown, Pennsylvania

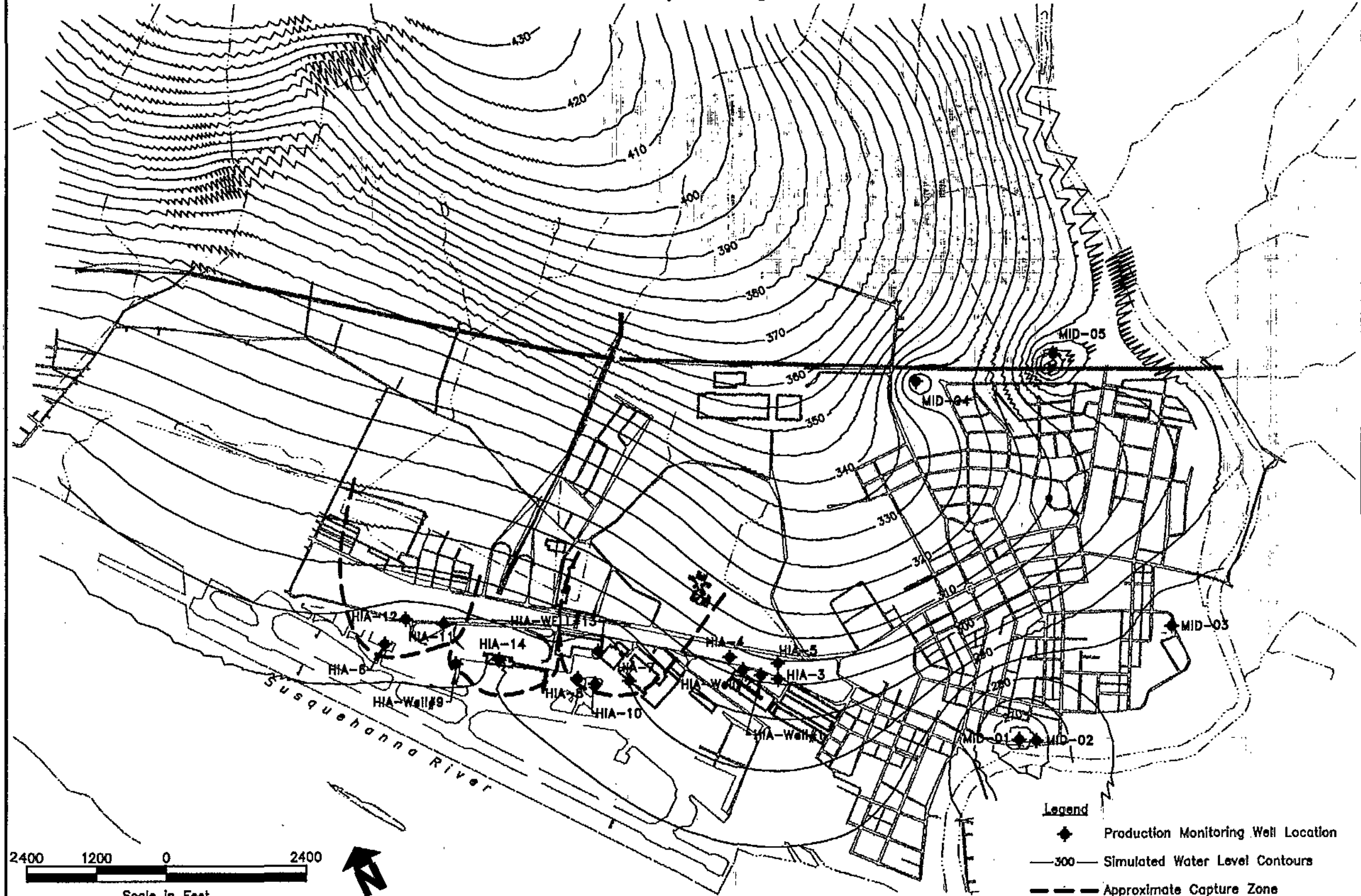


Figure L-27
Simulated Water Levels for Scenario 3 Layer 3
Middletown Airfield NPL Site
Middletown, Pennsylvania

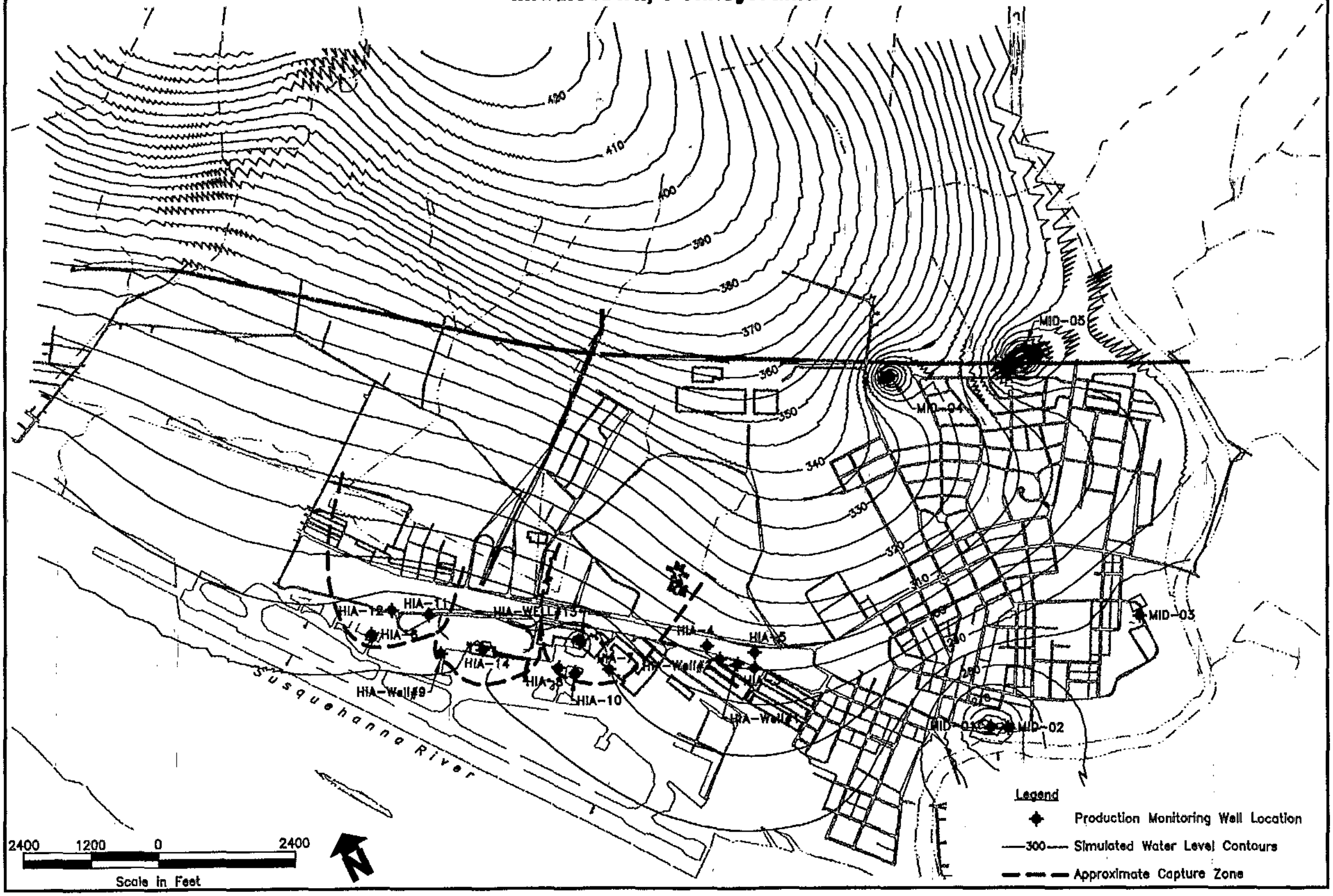
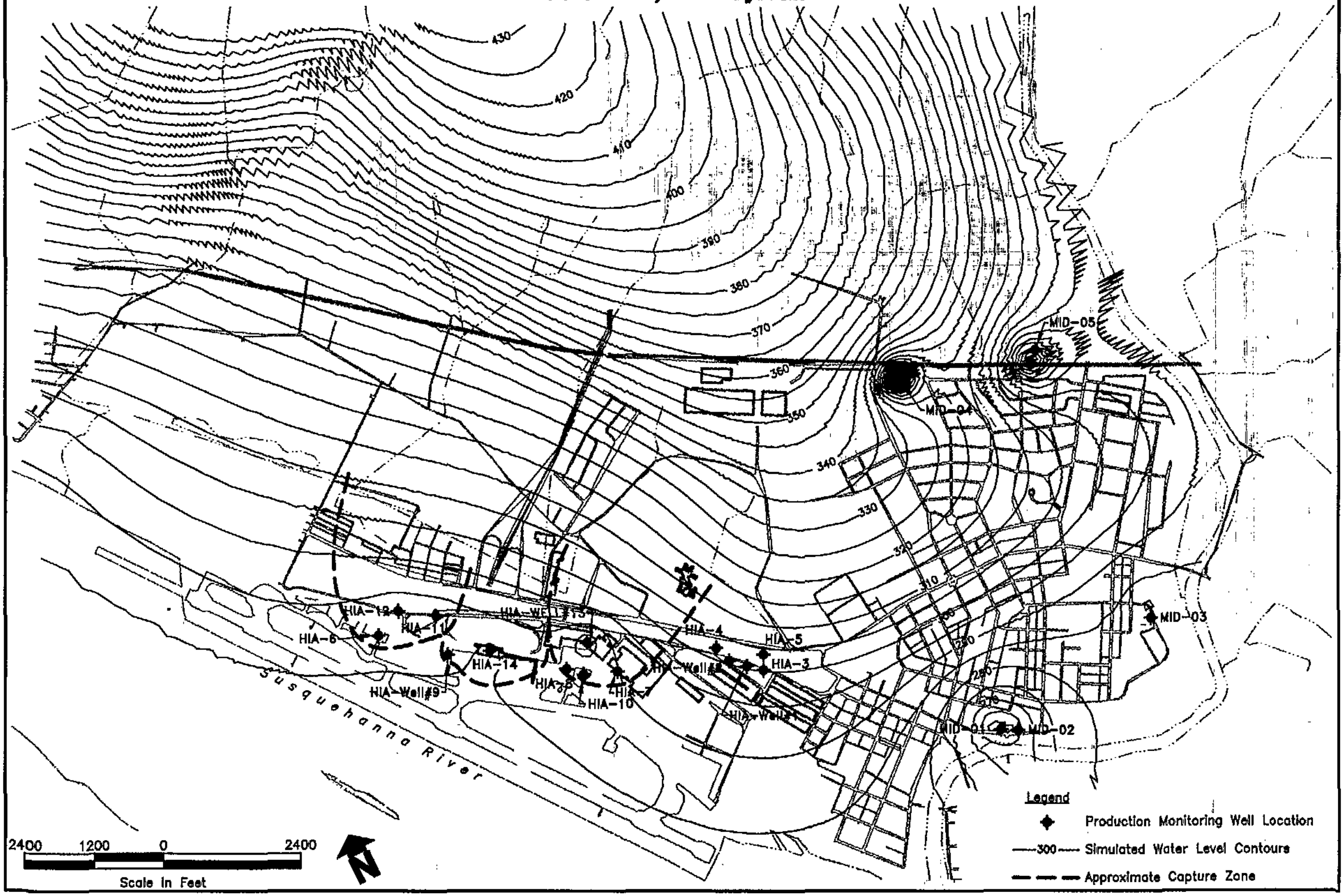


Figure L-28
Simulated Water Levels for Scenario 3 Layer 4
Middletown Airfield NPL Site
Middletown, Pennsylvania



L.11 *CONCLUSIONS AND RECOMMENDATIONS*

The MODFLOW model presented herein is a regional ground water flow model which has been calibrated to the May 1995 ground water levels collected during the SSI. The model is satisfactorily calibrated to evaluate the current hydraulic capture of the HIA production wells, and to develop and evaluate alternate pumping scenarios to contain the ground water.

The current average annual pumping rates of the HIA production wells provide an effective containment for most of the impacted ground water beneath the HIA.

The capture zone for layers 2, 3, and 4, in the bedrock aquifer, were essentially identical. This suggest that two-dimensional modeling, as described in Appendix K, is an acceptable approach to performing further capture zone analysis.

The calibration of the model did not meet the objective of one contour interval accuracy. Additional calibration time would be required to achieve this objective. The difficulty in achieving the objective is the result of heterogeneous aquifer conditions, strong vertical hydraulic gradients, and differences between the average pumping rates which have created a long term effect on water levels and the varying pumping schedule on which the HIA production wells operate. That is, if the wells were operated continuously at the same pumping rates (versus the current variable pumping schedule), the observed ground water levels would likely be closer to the simulated steady-state water levels. However the model was satisfactorily calibrated within the Industrial Area to achieve the project objective of evaluating the reconfiguration of the HIA production wells.

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DOC ID 132071
PAGE # 269

IMAGERY COVER SHEET
UNSCANNABLE ITEM

SITE NAME Middletown Airfield NPL Site

OPERABLE UNIT ______

ADMINISTRATIVE RECORDS- SECTION ______ **VOLUME** Vol. IV

REPORT OR DOCUMENT TITLE Focused Feasibility Study (FS) Report - Volume IV, Appendiced K & L

DATE OF DOCUMENT 01-Jul-96

DESCRIPTON OF IMAGERY Plate L.1 ModFlow Model Grid Over Site Map

NUMBER AND TYPE OF IMAGERY ITEM(S) 1 oversized map